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UNITED STATES DEPARTMENT OF AGRICULTURE
BULLETIN No. 1128

Washington, D. C. PROFESSIONAL PAPER February 20, 1923

DECAYS AND DISCOLORATIONS IN AIRPLANE WOODS

By

J. S. BOYCE, Pathologist
Office of Investigations in Forest Pathology
Bureau of Plant Industry

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INTRODUCTION.

The purpose of this bulletin is to enumerate and describe the more important decays and discolorations to which woods used in aircraft construction are subject and the conditions under which they occur. It is well known that the initial or incipient stages of decay—that is, the first steps in weakening wood—are indicated by discolorations, but wood is subject to many color variations from the normal not caused by wood-destroying fungi.

The value of recognizing the true nature of any given discoloration or other abnormality is immediately apparent, since such knowledge will permit the free use of wood which, though seriously reduced in value from an æsthetic standpoint by a disagreeable discoloration, is not mechanically weakened, while at the same time dangerous color variations can be detected. In the airplane industry, where the very finest quality of high-grade wood is demanded, and in which there is a maximum of unavoidable waste in the remanufacture of the lumber, it is imperative that no suitable material be wasted or diverted to another purpose, while at the same time it is equally important that all weakened material be excluded.

This bulletin first considers certain defects in airplane woods not due to decay, but which must be readily recognized in order to avoid

confusion. Next are described the various discolorations in airplane woods caused by mechanical injuries to the living trees, chemical reactions, harmless fungi, and decay-inducing fungi in relation to their actual effect on the strength of wood. In the case of those defects and properties which it is not within the province of this bulletin to discuss in detail, references to available literature are given.

GENERAL CONSIDERATIONS.

There are certain basic principles in the manufacture of high-grade lumber which should be most rigidly adhered to in the case of stock for airplanes. The purchaser should be certain that the manufacturer supplying his requirements is both willing and able to fulfill these conditions, so that defects very difficult to detect are not introduced.

When trees are felled the logs should be removed from the woods with reasonable promptness, because as soon as the timber is down it becomes subject to decay, sap-stain, checking, and the attacks of wood-boring insects. Leaving logs in the woods over winter is particularly poor practice. If the logs must be stored for any considerable length of time they should be kept in the pond, where the defects mentioned will be largely prevented.

After the logs are sawed the lumber should be carefully inspected and those pieces unsuitable for use in airplanes diverted to other uses. Next comes seasoning. Drying with artificial heat in dry kilns is preferable. The kilns should be of proper construction, so that the temperature and relative humidity can be completely controlled and the lumber brought to an average final moisture content of about 8 per cent, within the limits of 5 to 10 per cent (based on oven-dry weight), without checking or other injury. If it is necessary to store the dry lumber at the mill it should be placed in a dry shed, completely protected from the weather. The shed should have a board floor. Concrete, particularly if new, or dirt floors may give off considerable moisture. The stock should be shipped in box cars completely protected from moisture. When it reaches the factory the lumber should be shop seasoned; that is, placed in a room under uniform shop conditions, for about two weeks. During the entire process of manufacture the stock should be carefully protected from the absorption of moisture. Piling lumber or partly fabricated parts on damp floors or under the drip from steam or water pipes are two not uncommon offenses.

In case it is impossible to kiln-dry the stock, air drying must be resorted to. As a rule it is not possible to get the moisture content below 11 per cent by this process, except in arid regions. When the lumber comes from the saw it may be necessary to dip it in a chemical solution to prevent sap-stain in regions where lumber is especially subject to this discoloration; but under any conditions the stock should be carefully open-piled on elevated foundations to assure a circulation of air throughout and only sound, bright, thoroughly seasoned stickers used between courses. The piles should be properly slanted and roofed, so that rain will run off and not soak the lumber. To pile lumber closely, without proper circulation of air throughout the piles, results in some cases in warping, sap-stain,

and, ultimately, decay. Then, too, it is almost impossible for the stock in the center of the pile ever to become properly dry.

At best, however, air drying is a matter of months, even with softwoods, while proper kiln drying can be accomplished within one to three weeks or so, depending on the thickness of the stock. As a rule, hardwoods both kiln-dry and air-dry more slowly.

Air-dried stock should be shipped in the same manner as kiln-dried and handled in the same way at the factory, except that it must be kiln-dried to the proper moisture content before it is conditioned in the shop.

The principles given briefly in the foregoing paragraphs, together with their application and underlying reasons, are brought out in detail in the following pages.

WOODS USED FOR AIRPLANE CONSTRUCTION.

The most important wood for aircraft construction is spruce, including red, white, and Sitka spruce (*Picea rubens* Sarg., *P. canadensis* (Mill.) B. S. P., and *P. sitchensis* (Bong.) Trautv. and Mayer), but of these Sitka spruce, on account of its much larger size and the consequently greater quantity of clear lumber that can be obtained, is paramount. By far the greatest proportion of the lumber entering into the construction of most present-day airplanes is spruce or one of its substitutes. The combination of strength properties with light weight found in spruce is not duplicated in any other wood. Most of the beams in the directing surfaces are preferably of spruce or a soft wood, as are many of the struts, and these parts account for the bulk of the timber in an airplane.

An excellent substitute for spruce is Port Orford cedar (*Chamaecyparis lawsoniana* (Murr.) Parl.), which is slightly heavier. Unfortunately the supply of this splendid wood is decidedly limited. Douglas fir (*Pseudotsuga taxifolia* (Lam.) Br.), though much heavier than spruce, is an extensively used substitute. Other woods which can play some part in this way or may be used for special purposes where a softwood is needed are western white pine (*Pinus monticola* Dougl.), sugar pine (*P. lambertiana* Dougl.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), white fir (*Abies concolor* (Gord.) Parry), amabilis fir (*A. amabilis* (Loud.) Forbes), noble fir (*A. nobilis* Lindl.), yellow or tulip poplar (*Liriodendron tulipifera* Linn.), basswood (*Tilia americana* Linn.), incense cedar (*Libocedrus decurrens* Torr.), and western red cedar (*Thuja plicata* Don.). Certain parts of an airplane frame as a rule are made from hardwoods. In such parts great strength and toughness are requisite. Here, commercial white ash[1] stands supreme. For example, it is unsurpassed for longerons in those fuselages not constructed wholly or mostly of veneer. Black ash (*Fraxinus nigra* Marsh), which does not possess sufficient stiffness for use in highly stressed parts, can be distinguished from white ash (*2; 30*, p. 47; *68*, p. 62).[2] White oak,[3] hard maple (*Acer saccharum* Marsh), and

[1] Commercial white ash includes white ash (*Fraxinus americana* Linn.), green ash (*F. lanceolata* Borkh.), blue ash (*F. quadrangulata* Michx.), and Biltmore ash (*F. biltmoreana* Beadle).

[2] Serial numbers (italic) in parentheses refer to "Literature cited" at the end of this bulletin.

[3] White oak as used here includes white oak (*Quercus alba* Linn.), bur oak (*Q. macrocarpa* Michx.), cow oak (*Q. michauxii* Nutt.), and post oak (*Q. minor* (Marsh) Sarg.).

rock elm[4] are sometimes used instead of white ash. Hickory,[5] so far, has been principally used for tail skids. The two finest woods for propellers are black walnut (*Juglans nigra* Linn.) and true mahogany (*Swietenia mahagoni* Jacq.), also known as Central American mahogany. Other species commonly used are yellow birch (*Betula lutea* Michx. f.), sweet birch (*B. lenta* Linn.), African mahogany (*Khaya senegalensis* A. Juss.), black cherry (*Prunus serotina* Ehrh.), hard maple, white oak, and yellow poplar. However, a number of other woods are occasionally utilized, and in the future a wide variety of species will probably be admitted. European designers even now are less exacting in this respect, sometimes using two species of wood in the same propeller, which on the whole is considered poor practice in this country.

TABLE 1.—*Distribution of wood in airplanes, showing the service requirements and the adaptation thereto of the different grades of the several species.*

Designation of assembly and name of part.	Species of wood and quality designation (grade).												
	Spruce.	Douglas fir.	Port Orford cedar.	Basswood.	Tulip poplar.	White pine.	White fir.	Western hemlock.	White ash.	White oak.	Hard maple.	Rock elm.	Hickory.
Main and center planes, ailerons, stabilizer, elevator, rudder, and fins:													
Beams, solid	A	A	A	....	A	A	A	A	....	....	....	....	....
Beams, box	A	A	A	....	A	A	A	A	....	....	....	....	....
Filler blocks	C	C	C	C	C	C	C	C	....	....	....	....	....
Fillet strips	B	B	B	B	B	B	B	B	....	....	....	....	....
Panel blocks—													
Brace blocks	C	C	C	C	C	C	C	C	C	C	C	C	C
Corner blocks													
Spacer blocks													
Reinforcing blocks													
Rib webs, solid	B	B	B	B	B	B	B	....	....	....	....	....	....
Rib webs, compression (solid)	A	A	A	A	A	A	A	....	....	....	....	....	....
Compression struts	A	A	A	....	A	A	A	....	....	....	....	....	....
Cap strips	A	A	A	A	A	A	....	....	....	....	....	....	....
Trailing edge—													
Straight	B	B	B	....	B	B	B	B	....	....	....	....	....
Bent	....	....	....	....	....	....	....	....	A	A	A	A	A
Entering edge—													
Straight	B	B	B	....	B	B	B	B	....	....	....	....	....
Bent	....	....	....	....	....	....	....	....	A	A	A	A	A
Gussets	B	B	B	....	B	B	....	....	....	....	....	....	....
Masts	A	A	A	....	A	A	....	....	....	....	....	....	....
Stringers	B	B	B	....	B	B	B	B	....	....	....	....	....
Interplane struts	A	A	A	....	....	....	....	....	A	A	A	....	....
Center section struts	A	A	A	....	....	....	....	....	A	A	A	....	....
Fuselage:													
Longerons—													
Straight	A	A	A	....	....	....	....	....	A	A	A	A	....
Bent	....	....	....	....	....	....	....	....	A	A	A	A	....
Struts, vertical, and horizontal—													
High stress	A	A	A	....	A	A	A	A	B	B	B	B	....
Low stress	B	B	B	....	B	B	B	B	....	....	....	....	....
Struts, diagonal	B	B	B	....	B	B	B	B	....	....	....	....	....
Supports, heavy	A	A	A	....	A	A	A	A	A	A	A	....	....
Supports, light	B	B	B	B	B	B	B	B	B	....	....	....	....
Brace blocks	B	B	B	B	B	B	B	B	B	B	B	B	....
Stiffeners	B	B	B	B	B	B	B	B	....	....	....	....	....
Cleats	....	....	....	....	....	....	....	....	C	C	C	C	....
Furring strips	B	B	B	B	B	B	B	B	....	....	....	....	....
Floor and seat boards	C	C	C	C	C	C	C	C	....	....	....	....	....
Cradle slats	C	C	C	C	C	C	C	C	....	....	....	....	....
Seat rail	A	A	A	A	A	A	A	A	....	....	....	....	....
Tail post	A	A	A	....	....	....	....	....	A	A	A	....	....
Tail skid	....	....	....	....	....	....	....	....	A	A	A	A	A
Landing chassis:													
Struts	A	A	A	....	....	....	....	....	A	A	A	A	....
Stream lining	C	C	C	C	C	C	C	C	....	....	....	....	....

[4] Rock elm includes rock elm (*Ulmus racemosa* Thomas) and the more dense stock of both white elm (*U. americana* Linn.) and slippery elm (*U. pubescens* Walt.).

[5] The true hickories include mockernut hickory (*Hicoria alba* (Linn.) Br.), shellbark hickory (*H. laciniosa* (Michx. f.) Sarg.), pignut hickory (*H. glabra* (Mill.) Br.), and shagbark hickory (*H. ovata* (Mill.) Br.).

Table 1, which is an adaptation of specification 15037–B of the Bureau of Aircraft Production, shows where the various woods may be used in an airplane and the quality desired. The symbol *A* indicates a grade of wood of the very highest quality and free from all injurious defects; grade *B* demands a quality of wood similar to grade *A* in all respects except that a little tolerance is allowed in regard to straightness of grain and specific gravity; wood of grade *C* is used in parts where little strength is needed and may contain various defects, provided the piece is strong enough for the purpose intended.

These woods are not the only ones used for airplanes, but they are the most important. Others are mentioned here and there in this bulletin. It can be predicted that, with a growing scarcity of the more desirable species and an increase in our knowledge of the properties of other species, woods little or not at all used at present will become of importance. For a full discussion of this entire subject, the reader is referred to other sources (*60; 69*, p. 34–40).

GENERAL DEFECTS OF AIRPLANE WOODS.

It is impossible to thoroughly understand wood without a working knowledge of its structure and mechanical properties. This is more difficult to attain than with most other materials of construction, for wood, instead of being a relatively simple and more or less homogeneous compound, is a highly complex organic structure whose chemical composition is even now none too well understood. The discussion in the following pages will be much clearer to the reader provided he has such knowledge. There are a number of valuable publications which may be referred to in this connection (*30*, *45*, *47*, *48*, *68*, *69*).

Besides decay, there are other defects which reduce the strength of timber, and these must be given due consideration. Wood may be inherently weak because of its structure, it may be injured by some process of manufacture, or the trouble may be due to faulty design or assembly. Such defects in relation to airplane woods have been discussed in various publications (*42; 46; 68*, p. 15–20; *69*, p. 11–22), but a review of the more important of these is essential here, since by the uninitiated some of them are confused with decay.

GRAIN.

One of the most common defects in airplane woods is an excessive slope of diagonal or spiral grain. Since any deviation from straight grain is accompanied by a reduction in strength, the requirements in this respect are very exacting, a deviation from straight grain of more than 1 inch in 20 inches rarely being allowed for any highly stressed portion of an airplane, although this may be reduced to 1 inch in 12 in portions of less severe stress. A discussion of the methods to be employed in detecting this defect, together with its effect on strength, may be found in several publications (*31; 42*, p. 8–14; *68*, p. 15–16; *69*, p. 11–20).

SPECIFIC GRAVITY.

Brashness or brittleness in wood is another common defect. These synonymous terms denote a lack of toughness in wood to which they are applied. Brash wood is usually low in strength, and when

tested by bending fails with a short break instead of a splintering fracture. This is one indication of decay, but not all wood showing such defect is decayed. Too often when wood appears to be somewhat brash and develops less than the normal strength, instead of making a serious attempt to determine the real source of the difficulty the cabalistic term "dry-rot" is uttered, and the case is settled, often resulting in the loss of good material, while the trouble goes on unchecked. Even if the wood be decayed, it most probably is not dry-rot, which term to the pathologist embraces a definite type of decay caused by a certain fungus. Let us consider a few of the more important causes of brashness, aside from decay, in aircraft woods.

The primary requisite of wood for use in airplanes is that it must be of specific gravity high enough to give the necessary strength. It has long been known that an increase in strength of any species of wood goes with an increase in specific gravity, and it has finally become possible accurately to express this relation for the various strength properties, so that if the specific gravity of a given piece of wood is known it is possible quite accurately to derive its strength under various stresses (*41*). No matter how perfect a piece may be in other respects and free from all other defects, if it is below the minimum specific gravity it should not be used. These minimum figures have been carefully worked out for the more important airplane woods (*68*, p. 21; *69*, p. 26). Wood of low specific gravity is naturally somewhat brittle, and for this reason is often erroneously considered as slightly decayed. While the actual specific gravity of the wood substance in various species is practically the same (*13*), having a value of 1.54, the porous nature of the wood is such that most commercial species range from 0.3 to 0.6. In other words, only one-fifth to three-fifths of a unit volume of wood is occupied by wood substance; the remainder is air.

It is self-evident that a density or specific gravity determination of every individual piece of wood to be used for a primary member in an airplane is out of the question. Neither is it necessary. The most reliable index of specific gravity, without making an actual test, is the ratio of spring wood to summer wood per annual ring. This is best seen on the cross or end section after it has been smoothed off with a sharp knife or a high-speed miter saw. In the softwoods the summer wood is the darker of the two bands composing each annual ring, as is shown in Figure 1, which illustrates cross sections from two wing beams of Douglas fir, one of average and the other of low specific gravity. In the ring-porous hardwoods (ash, for example) the summer wood appears more solid and very much less porous than the spring wood, but in the diffuse-porous hardwoods (such as birch) this is often very difficult to determine. For Douglas fir a minimum specific gravity of 0.47 has been established for high-stressed members, but this can probably be reduced to 0.45 with perfect safety when used as a substitute for spruce. As a rule, wood of this species with less than 6 or more than 30 annual rings per inch, measured radially on the cross section, falls below the minimum specific gravity. The former usually comes from the center of the tree, where the wood is rapid growing and brash, while the latter is the slow-grown soft "yellow fir" so characteristic of the outer layers

of very old trees. If each annual ring is composed of approximately one-third or more of summer wood the piece possesses the necessary strength. In those pieces with very narrow annual rings, in which the summer wood is indicated by a mere dark line at the outer edge of each annual ring, the wood is very soft and weak, often having a specific gravity as low as 0.34 (Fig. 1).

Sometimes the proportion of material of low specific gravity in Douglas fir airplane lumber is exceedingly high. The writer has seen several consecutive carload lots of selected wing-beam stock at one factory in which from 25 to 50 per cent of the pieces in each car were below the minimum specific gravity. The stock was cut from old

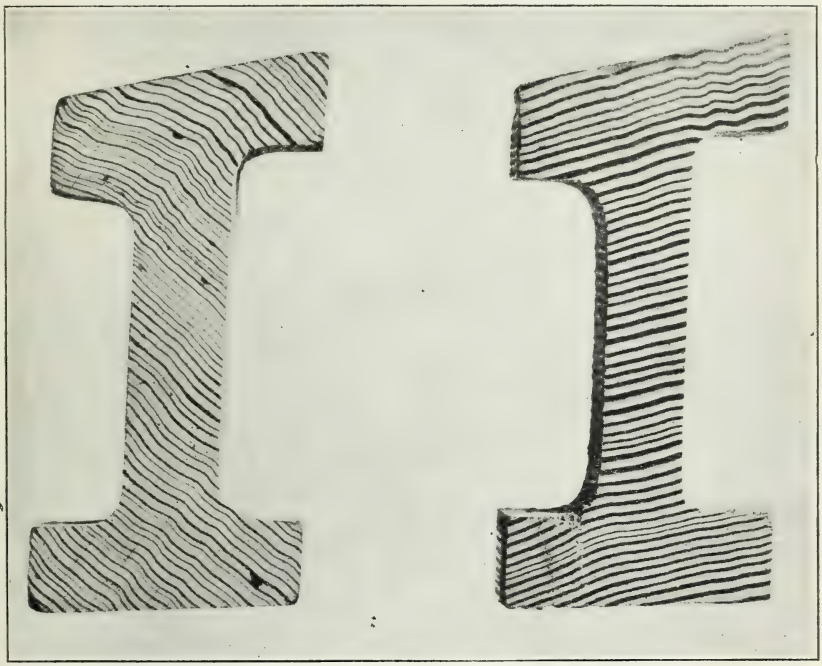

FIG. 1.—Cross sections of wing beams of Douglas fir of average and low specific gravity. The large proportion of summer wood, indicated by the dark bands, in the piece of good specific gravity (on the right) in comparison with that in the piece with low specific gravity (on the left) is plainly shown.

slow-grown trees, which yield the "yellow fir" so much preferred by the trade, but which invariably contain a large percentage of material of low specific gravity not suitable for aircraft or any other type of construction where high strength is requisite.

The same general relations hold good in Sitka spruce. Here, again, if the annual rings are too few or too many per inch, they indicate wood of low density. The minimum specific gravity for this species is established at 0.36.

It is often difficult to approximate the specific gravity by visual examination of the proportion of summer wood per annual ring in the case of those pieces close to the minimum density permitted in softwoods. There is considerable chance for error even with Douglas fir, but with spruce this is increased, owing to the fact

that the summer wood and spring wood merge into each other, not being sharply delimited as in Douglas fir. With experience it is quite feasible to judge with accuracy the relative specific gravity of many of the pieces, leaving the doubtful ones for an actual test or to be worked up along with those below the minimum into parts less highly stressed. In making tests to determine the specific gravity it is not necessary to use the time-consuming immersion method. The pieces can be cut fairly regularly, oven dried, and the volume ascertained by measuring to the nearest half millimeter or to the nearest sixty-fourth of an inch. The weight should be obtained as usual. The writer has tested this method extensively and found the limit of error rarely over 0.01. In most cases the result will not vary from that obtained by the immersion method. This method can not be used on irregularly shaped pieces, however.

In the ring-porous hardwoods, such as ash, it is very easy to determine the relative proportions of spring and summer wood in each annual ring. Here the condition is the reverse of that found in the softwoods. About three-fifths or more summer wood per annual ring in the case of white ash is necessary to give the strength required by the minimum specific gravity of 0.56. Wood with few annual rings to the inch in white ash has a high specific gravity, and this, as a rule, decreases as the number of rings per inch increases. Wood with 20 to 25 annual rings or more to the inch is usually worthless if strength is a requisite. The relations just discussed are fairly constant throughout the ring-porous hardwoods, such as white oak, rock elm, and hickory.

A large proportion of summer wood is not always an indication of strength in white ash. The notable exception to this rule is pumpkin ash, so called by the trade. This ash has remarkably broad bands of summer wood in the annual rings. These rings are often half an inch broad and contain only one or two narrow lines of pores in the spring wood, but the specific gravity of the wood is low, and when tested in static or impact bending it breaks with a brash, brittle failure under a light load. It can readily be detected by cutting with a knife, yielding softly without the resistance offered by good ash. When finished it has a waxy white, cream, or light-brown color in tangential section and can be readily dented with any hard blunt instrument. In cross section the pores in the summer wood sometimes appear as small brown, rather indistinct spots.

Pieces may be found with almost the same appearance as pumpkin ash which when tested with a knife prove to be hard and tough, with a good specific gravity; or, again, both hard and soft wood may be found in the same board.

As nearly as can be ascertained from hearsay evidence, this pumpkin ash is not confined to a particular tree species, but may be found in any of the white-ash group when grown under swampy conditions in the southern part of the range. It does not necessarily occur, but when it does the central portion of the butt logs or even the entire trunk may be composed of such wood. Pumpkin ash has been assigned by botanists as the common name for one definite tree species (*Fraxinus profunda* Bush), but the name as applied in the lumber trade denotes white-ash wood having the characteristics above described without regard to species.

It is quite difficult to judge the specific gravity of diffuse porous hardwoods by visual examination except in those pieces patently very low or very high. Actual specific-gravity determinations will have to be used to a greater extent when handling this class of woods.

In examining a piece of wood of any considerable length to determine its specific gravity, care must be used to examine it throughout. Pieces in which the grain is not perfectly straight may have high specific gravity in one portion and a low density in another, as attested by the percentage of summer wood. This is due to the fact that trees may not develop wood of the same or nearly the same specific gravity throughout their life. Such a condition is not at all uncommon in white-ash longerons, and it must be remembered that any given piece of wood is no stronger than its weakest portion.

As a general rule, airplane timber should be purchased under specifications so worded in regard to the ratio of spring wood and summer wood per annual ring and number of annual rings per inch of radius as to reject at the source of supply most of the stock of low specific gravity.

COMPRESSION WOOD.

Occasional pieces of wood of unusual growth are encountered. The annual rings are very broad, with an abnormally large proportion of summer wood per annual ring, and there is little contrast between the spring wood and the summer wood. The specific gravity is very much higher than that of normal material. The abnormal growth is supposed to be due to the fact that the tree or portion of the tree from which the piece came had been under some long-continued unusual stress or had been in an unusual position. The term "compression wood" is usually applied to material of this nature. The writer remembers particularly a spruce wing beam with six annual rings per inch of radius, 75 per cent or more of summer wood per annual ring, and a specific gravity of 0.85. Since the usual specific gravity of spruce used is about 0.40, it can readily be seen that the weight of this wing beam was more than double the normal. Compression wood is not confined to spruce, but may be found in other soft woods. This type of wood is not desirable. Its strength properties are uncertain, and its shrinkage does not correspond to that of normal wood, the longitudinal shrinkage being several times as great, while the radial and tangential shrinkage is very much less. The excessive weight is also a factor that must be considered in a delicately balanced machine.

STEAMING AND BENDING.

Wood may be rendered brittle or otherwise injured by steam bending if this is not properly done. It is necessary to bend certain parts of an airplane frame in this way in order to obviate the initial stresses which would result if these members were simply sprung into place. This should not be attempted on thoroughly air-dry or kiln-dry material, because wood once dried is weaker when brought back to a higher moisture content, and in addition such material has a tendency to spring back after the clamps are removed if it was not thoroughly resoaked. As a rule, wood with less than 18 per cent of moisture based on oven-dry weight should not be steamed and bent.

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Too high temperatures in the steam box will make wood brittle, seriously weakening it. Steaming should be accomplished at atmospheric pressure and for a period not to exceed six hours. Higher pressure means higher temperatures and weakened wood. Most hardwoods are more or less discolored by this process, assuming a dead-gray color, but this does not indicate injury. White oak may change to a blackish brown. White ash becomes a dead-gray color, on which a bluish gray discoloration may appear. Elm also takes on this gray shade to some extent. The change in color is very much less noticeable in the soft woods.

Soft woods should not be steamed and bent, because they are very susceptible to injury by this process. When tested, the bent portion will be very weak and brash. A close examination will reveal numerous slight compression failures on the inner curve of the bend. Spruce is particularly subject to this type of injury.

SEASONING.

It is well established that a decrease in the moisture content of wood after the fiber saturation point is reached results in marked progressive increase in the strength of wood, accompanied by a decided shrinkage (*63*). The fiber saturation point is the condition at which the cell walls are completely saturated, or, in other words, have absorbed the maximum percentage of water which they can hold, but the cell cavities are empty. For two reasons, then, to increase the strength and to prevent subsequent shrinkage when the pieces have been worked to size or even assembled, it is essential that airplane timber be dried or, as it is commonly termed, seasoned. This may be done by air drying, that is, natural seasoning in the air, or by kiln drying, that is, seasoning with artificial heat (*4*, *12*, *64*, *65*, *66*, *70*).

As a result of improper seasoning, particularly that which occurs unevenly or too rapidly, checks, which are small longitudinal splits, may occur in the wood. Almost invariably these are on the tangential face, since wood as a rule shrinks about twice as much in the direction of the annual rings as it does radially or across them. The longitudinal shrinkage (with the grain) is so slight that it usually has no effect. Checks are decidedly weakening, but fortunately are easy to recognize.

Airplane wood is usually kiln dried, because the seasoning process can be better controlled than in air drying; it is more rapid, a lower moisture content can be attained, and there is less tendency for kiln-dried wood to shrink and swell with subsequent changes in the humidity of the air. Extensive tests have been made on the effect of artificial seasoning (*73*). Kiln drying when not properly done is a source of serious injury. Temperatures that are too high or proper temperatures that are combined with humidity that is too low may markedly weaken a charge of lumber, particularly if these conditions are maintained for some time. The detection of such injury, when not severe, is very difficult. Hence, it is highly important that self-recording instruments showing temperatures and relative humidities at all times be properly installed in the kilns and that these be calibrated from time to time. In pronounced cases the lumber will readily reveal its brittle nature when picked with a knife blade.

In all cases where it can not be determined satisfactorily by other methods, representative pieces should be selected for impact bending. This test above all others most readily reveals brittleness in wood. But the test must be made, or at least the results and breaks reviewed, by some one experienced in this method of testing and thoroughly conversant with the mechanical properties of wood.

COMPRESSION FAILURES.

Compression failures may be due to abnormal stresses on the standing tree (from a wind of unusual velocity, for example), to shocks in felling the trees, or to injury during the process of manufacture. Figure 2 shows a compression failure, probably caused when the tree was felled, in a section from an unfinished wing beam of Sitka spruce. As an example of injury during the course of manufacture, it might be mentioned that when a large number of wing beams, improperly piled, are transported on a car or wagon the weight and jar sometimes cause such failures in beams near the bottom of the pile.

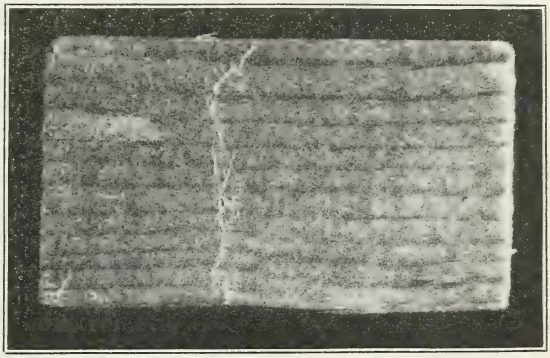

FIG. 2.—Section from an unfinished wing beam, showing a compression failure in Sitka spruce which probably occurred when the tree was felled.

The smaller compression failures are not easy to detect. They appear as small whitish wrinkles or irregular lines across the face of the piece, at right angles to the grain. A hand magnifier is often necessary to bring out the finer failures distinctly. The more pronounced failures appear as rather rounded ridges resulting from the "buckling" of the wood fibers under stress.

Compression failures are quite detrimental to the strength of wood, particularly as regards bending strength and shock-resisting ability. Material showing compression failures must not be used in parts where strength is required. One visible small compression failure usually indicates the presence of others.

Members with a small cross section are sometimes subjected to a rough test which makes the wood appear to be brash. It is well known that beams when placed in static bending characteristically fail first in compression, that is, in the fibers between the center (neutral plane) and the top of the beam. Hence, when a spruce longeron, for example, is supported at both ends and a load applied in the center, slight and practically invisible compression failures may result. Such failures appear as tiny whitish lines or wrinkles on the surface of the wood. If the member is then turned over and the load again applied until failure occurs, the break will be sharp and straight across with no splintering, typical of a compression break. This test should not be applied to softwood longerons, particularly spruce, since the resulting breaks will nearly always be

short and sharp and may be confused with breaks in brash wood. By turning the member over after the first weight is applied, the compression side, already partially failed, becomes the tension side under the new load; and when the new compression side fails, the tension side, already fractured squarely across, fails with it. To test the resiliency of such members, apply the load on one side only, and do so with moderation.

SHAKES.

Shakes are long tangential cracks or separations in the wood fiber. They are the result of an actual rupture of the wood due to wind, felling stresses, or other causes and are exceedingly detrimental to strength. Old shakes which have occurred while the tree was still standing are often stained and readily visible to the naked eye. This is also true where lumber has been exposed to the weather and dirt has filtered into the cracks. But where they are neither discolored nor opened up the rupture is not so easily detected.

PITCH POCKETS.

Pitch seams or pockets are lens-shaped cavities or openings between the annual rings. They contain resin or pitch either in solid or liquid form; hence the name. These defects result from injury to the living tree, but the cause of injury is as yet unknown. Pitch pockets may indicate more serious wounds. They are very common in Douglas fir, but may be found in other resin-producing softwoods, including spruce.

While pitch pockets reduce the strength of wood, the reduction is not as serious as is generally supposed. General specifications regarding the presence of these defects have been worked out for wing beams of spruce and Douglas fir (*69*, p. 21).

WORM HOLES.

Worm holes are caused by the larvæ of three main types of wood-boring insects. The powdery or granular matter, the excrement or frass of either the adults or the "worms," or larvæ, with which these galleries or burrows are usually filled, need not be confounded with decay, since there is no difficulty in separating the two defects. In decay the transition from the soft, spongy, or friable wood to the normal hard material is gradual, while in the worm holes, usually circular or somewhat flattened when seen in cross section, the line between the firm wood and the frass or finely excreted wood is very sharp.

(1) Ambrosia beetles or "pinworms." The small adult beetle bores into the green saw log or green lumber and deposits its eggs. The larvæ hatching from these eggs extend other burrows at an angle from the parent galleries. Moisture is necessary for this type of insect. There may be a blackish discoloration extending around the galleries, particularly those in the sapwood. This is the result of the activity of a wood-staining fungus which does not cause decay in the wood and therefore need not be considered as weakening the material.

(2) Borers. The adults of borers, as a rule, require bark under which to lay their eggs. The larvæ hatching from these eggs burrow under the bark through the sapwood and sometimes into the heartwood; the holes are often large.

(3) Powder-post beetles. Powder-post beetles cause the most dangerous type of defect, and their presence may be detected by fine, powdery droppings coming from the wood. The eggs are laid either in the pores of the wood or under the bark, depending upon the type of insect causing powder post.

Worm holes not only weaken the wood, but the presence of the larvæ of powder-post beetles in the wood may render it unsafe. Ambrosia beetles or borers already in the wood can be killed by the ordinary dry-kiln process, but certain types of powder-post beetles require higher temperatures. It is much simpler to prevent attack, and this can be done by slight modifications in business management.

Full information on these and other insect defects can be obtained from the Bureau of Entomology, United States Department of Agriculture.

CHARACTERISTICS OF SPECIES.

Different woods have certain inherent qualities which must be recognized. Douglas fir has a decided tendency to splinter. The separation usually occurs along the annual rings in the spring wood adjacent to the summer wood. It is quite probable that this characteristic can be accentuated by excessive steaming with high temperatures during kiln drying, since it has been shown (*61*) that certain softwoods in which the spring wood is sharply differentiated from the summer wood, in which category Douglas fir belongs, have the spring wood weakened more easily than the summer wood by prolonged boiling. On account of this tendency of Douglas fir to splinter, aside from other reasons, Sitka spruce and Port Orford cedar are more desirable.

White elm can be readily steamed and bent, but it usually warps and twists badly in drying. Douglas fir is very subject to splitting when nailed, while basswood is one of the least troublesome species in this respect. Black ash is low in stiffness. Other examples might be cited, but these are sufficient to show that the failure of a wood to meet certain requirements may be unavoidable.

FAULTY DESIGN AND ASSEMBLY.

As an example of faulty design the following instance may be cited. In one of the types of combat planes constructed in the aircraft factories of this country two horizontal bolts were placed directly through the neutral plane in each upper front longeron of Douglas fir. A fitting was hung on the head of these bolts and two opposed high-tension wires, pulling at right angles to the direction of the grain in the longeron, were attached to the fitting. While the ship was subjected to shocks and jars which occur particularly during landing, these wires were in very unequal and irregular tension, varying from loose to very tight, and the strain on the longeron was exactly the same as if a chisel blade had been inserted through the neutral plane and the handle was being jerked sharply up and down. On the test flight of the first ships built the longerons did the obvious thing; they split in both directions from the bolts for a distance of a few inches to 2 feet. The failure was promptly blamed on the wood, which was assumed to be either weakened by decay or faulty kiln drying, instead of on the faulty design, where it belonged. Such mistakes arise from the lack of knowledge of the mechanical properties of wood on the part of the designer.

Incorrect assembly also plays a part in the unjust condemnation of perfectly good wood. One of the most common occurrences was to have interplane struts of Douglas fir or spruce, especially the

latter, reported as being made from decayed or "dead" wood. This was characterized by the fact that the struts, after assembly, if struck sharply on the side near the middle, would "bow" and remain in such position. If struck then on the opposite side the "bow" might reverse, but the strut rarely straightened up. This condition results from such an excessive tightening of the drift and flying wires that the struts acting as posts between the wings are placed under such a heavy compression load that they are just on the point of failure, hence the inability to straighten up after bowing. Needless to state, such a condition is dangerous.

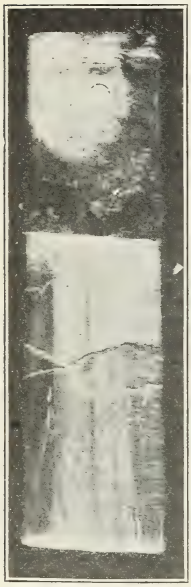

FIG. 3.—Head of a fuselage strut, showing a compression failure in Sitka spruce caused by an excessive tightening of the tension wires in the fuselage.

Figure 3 shows a compression failure in the head of a vertical fuselage strut due to severe tightening of the tension wires in the fuselage. This failure occurred before the machine had left the factory floor.

In the foregoing pages no attempt has been made to specify all the defects in airplane timber aside from decays or discolorations, or to describe fully those mentioned. The writer desires merely to call the attention of the reader to defects that can receive only passing mention or must be omitted entirely, so that, if interested, he can become conversant with these through the references cited.

COLOR COMPARISONS.

Color is a natural characteristic of wood while still in the living tree. For the first few years after formation wood is white or nearly so, and finally when the sapwood is transformed to heartwood a decided color change takes place in most woods, while in some the change is negligible. In such species as redwood (*Sequoia sempervirens* (Lam.) Endl.), incense cedar, Douglas fir, juniper (Juniperus), white ash, true mahogany, and white oak there is a decided contrast between the light-colored sapwood and the dark heartwood, while in spruce, fir, western hemlock, and yellow buckeye (*Aesculus octandra* Marsh) the heartwood more nearly approaches the sapwood in color, and in some cases it is difficult to distinguish between the two. Color is not always uniform in the heartwood. It is necessary to be thoroughly acquainted with woods to be able to recognize normal color variations at a glance.

Color should always be observed on a freshly cut surface and the surface (whether radial, tangential, or cross) recorded when making permanent observations. All woods change color on exposure to light and air (*54*), the most noticeable change occurring in the lighter colored woods, particularly of the conifers. The first change is a yellowing, then a graying, and finally in some conifers a decided browning. These color changes have no weakening effect on the mechanical properties of wood, since the discolored portion is a very thin surface layer and microorganisms play no rôle in this change

of color. Light is necessary. Ordinarily these color changes are deepened by direct sunlight, which has a greater influence on the color changes than diffused light.

Green wood usually differs in color somewhat from air-dry material of the same species, even on a freshly cut surface. There is a tendency for the more delicate tints to be obscured by drying. A system of color standards is at present sadly needed in describing colors of wood (*53*). Furthermore, the condition of the wood, that is, whether green, partly air dry, or fully air dry, invariably should be given consideration.

The heartwood of sugar-pine, eastern white-pine (*Pinus strobus* Linn.), and western white-pine lumber often becomes a pink, light-red, or vinous-red color upon air drying. This color is not confined to the surface layer, but is usually uniform throughout. No reduction in strength results. Wood of this kind is very pleasing to the eye, so it is often desired by pattern makers. This discoloration need not be confused with an incipient decay, since it is so uniform throughout. Furthermore, it terminates abruptly in a horizontal direction and does not shade off gradually into the normal light-brown or cream-colored wood.

Color is considered an index of strength properties (*14*, p. 359–360) in certain cases. The French marine department distinguishes two classes of European oak (*Quercus robur* L.), inferior wood (bois maigre) and good wood (bois gras). The former, which is straw yellow in color on a fresh cut, is much more subject to atmospheric influences; that is, it shrinks, swells, warps, twists, and splits more readily than the latter, which is pale brown to red brown in color. This is taken into account in specifying in what part of the construction the two types of wood shall be used. The Danish-Prussian marine specifications distinguish three colors of green oak wood, whitish yellow, brownish yellow, and reddish yellow, all three frequently with a tinge of gray. The first color on drying becomes straw-colored or sand gray, the second greenish brown, and the third reddish yellow or a dirty or dusty yellow-brown. It is considered that the unseasoned or fresh wood with any brownish color is decidedly poor in quality.

The foregoing seems to be somewhat contradictory. In the opinion of the writer, trusting to the vagaries of color is an exceedingly uncertain method by which to judge the strength properties of wood within a species or group and has nothing to recommend it as compared to the reliable index of the ratio of summer wood to spring wood per annual ring, which is particularly easy to judge in ring-porous woods like oak. There is a widespread opinion in regard to southern bald cypress (*Taxodium distichum* (Linn.) Rich.) that the darker the heartwood the more durable it is, but in reality the color of the heartwood makes no difference.

Most woods when dried after a prolonged immersion in water reveal a grayish, lusterless color, much like that caused by steaming (see p. 10). Oak changes to a blue-black or a gray-black color after such treatment.

Wood becomes a dirty gray to gray-black color after long exposure to the elements. This is well illustrated by unpainted poles, fence rails, posts, and shingles. The color change is caused by a number

of factors (*52*), but most important is a chemical reaction in which iron plays an important part. Timber is not weakened by this discoloration, since the action is confined to the surface.

In boards cut from red cedar (*Juniperus virginiana* Linn.) white streaks are frequently found mingling with the normal red heartwood. Such streaks are the white sapwood, the mingling being due to the irregular outline of the stem to which the heartwood conforms or to layers which never change to heartwood.

In Sitka spruce the heartwood has a light reddish tinge, slightly distinguishing it from the sapwood. Some trees of Sitka spruce, however, have a pronounced reddish or brownish pink heartwood, which is quite uniform throughout. The color difference is striking in a planed board or timber containing both heartwood of this kind and characteristic white sapwood. The same phenomenon undoubtedly occurs, in red and white spruce, where it would be even more noticeable, since the heartwood in these species is normally as light colored as the sapwood. This reddish heartwood is just as strong as wood of the usual color and can be safely utilized. The same condition is reported as being quite common in the Himalayan spruce (*Picea morinda* Link) in India (*16*, *29*).

The brown heartwood of incense cedar (*8*, p. 22–24) and western red cedar often has a reddish to purplish tinge, varying in intensity even in the same piece, while in other trees it may be completely lacking. It is entirely without significance in relation to the strength of wood so affected.

In certain softwoods color variations may be connected with changes in the rate of growth. In the heartwood of Douglas fir, which has a distinct reddish or orange-reddish hue, the reddish color may be strongly intensified in long regular bands. A careful examination will show that this color change is confined to a definite group of annual rings, narrower than those on both sides or containing a greater proportion of summer wood. The brown heartwood of the cedars also varies in this way. The so-called "yellow fir," from the slowly grown, exceedingly narrow ringed outer layers of the old coast Douglas firs, is another example. The origin of such variations can be readily recognized, since the color is confined to a definite group of annual rings.

Occasionally an apparent discoloration in heartwood may be due to the failure of the wood to change color uniformly during the transition from sapwood to heartwood. This has been noticed in white ash, Douglas fir, western red cedar, western larch (*Larix occidentalis* Nutt.), and other woods. The sapwood of white ash is white or straw colored, while the heartwood is grayish brown, sometimes with a reddish tinge. Hence, when the condition above mentioned is found, the grayish brown heartwood will contain sharply delimited straw-yellow areas of various sizes and shapes. The wood is not weakened. How to avoid confusing this condition with the initial stages of white-rot will be considered later.

Discoloration may be caused by dirt or dust. Surfaced or sanded white pine or sugar pine is sometimes found covered with tiny little grayish black streaks following the grain of the wood. A close examination will show that this is due to deposition of dust in the numerous resin ducts. This is especially apparent against the almost

white wood of these species, whereas in darker woods the streaks would pass unnoticed.

Burns or scorches in wood may occur from the use of high-speed saws if the saws are not set properly to provide sufficient clearance. Improperly set planing knives will produce the same effect. Usually such burns, appearing on the face of the piece as dark-brown to blackish blotches, are very superficial and can be planed off. The injurious effect is negligible. Deep burns, extending through a piece one-eighth or even one-fourth of an inch in thickness are rarely encountered and are usually confined to particularly susceptible woods, such as the white pines. These may result when a high-speed sander stops suddenly. The wood is injured and can not be used for highly stressed parts. Burns usually occur in the remanufacture of dry lumber and not on green lumber in the mills.

DISCOLORATIONS CAUSED BY WOUNDS.

The term "wounds" as applied to trees includes not only those scars by which the bark is removed from living trees, exposing the sapwood or heartwood with the death of the cambium over the exposed surface, but also those injuries by which the cambium is temporarily damaged but not killed. The cambium, which is very susceptible to injury, is the very narrow layer of delicate growing tissue of a tree situated at the junction of the living bark and sapwood. When this tissue is injured or killed, a healing or callusing process immediately begins which causes a dip or wave in the grain. Consequently, irregularity of grain in a timber often indicates proximity to a wound.

Wounds in living trees result from a variety of causes, among which may be mentioned fire, lightning, insects, birds, and man. All such injuries are usually accompanied by a discoloration of the wood, particularly the sapwood. Such discolorations are most intense in the hardwoods, especially in the sapwood of such species as white ash, hickory, maple, birch, and tulip poplar.

When the wood of a living tree is exposed to the air it dries out and changes color. In softwoods the change is to a grayish brown or dead-gray color, while in hardwoods the change ranges from a deep brown to almost black, most noticeable in the sapwood. This color change is an oxidation process. Although the wood is not weakened by this change, wound wood of this type should be avoided, owing to the fact that during its exposure to the air it often becomes infected by wood-destroying fungi and may be weakened by incipient decay.

LIGHTNING WOUNDS.

The general appearance of lightning injury is readily recognized. Spike tops and stag heads, together with the spiral wounds existing for many feet along the trunks of the trees, are unmistakable.

Besides such wounds, the cambium is very susceptible to electrical discharge and may be affected for some distance down the tree without any outward visible indications. This irritation to the cambium results in the formation of a layer of cells changed in both shape and structure from the normal. Often in the conifers an unusually large number of resin cells or resin ducts are formed within this injured

portion. In a short time the cell formation returns to normal. Ultimately, as the growth of the tree proceeds, these lightning rings, always following one definite annual ring, are deep within the wood, extending completely or partially around the circumference over a varying distance. When the tree is worked up for lumber certain of the boards may have such lightning rings extending completely through, both in width and length. Such a board then consists of two layers of wood held together by a zone of abnormal structure forming a plane of cleavage. Checking often occurs along this line, since the continuity of the medullary rays may be interrupted. Such checks are striking, since they invariably are tangential, following an annual ring on end section or radial face but not visible on the tangential face. This is not at all an uncommon defect in airplane timber. An abnormal number of resin ducts may be found in the annual ring following many types of mechanical injury, but for practical purposes there is no difference between such so-called traumatic resin ducts and the abnormal ducts formed as a result of lightning injury.

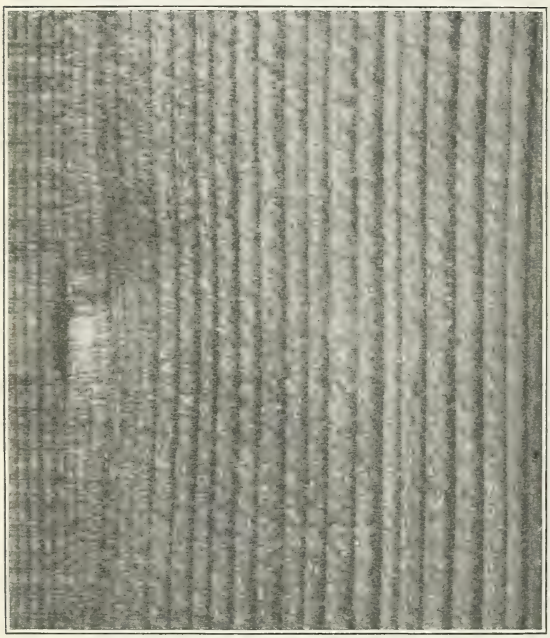

FIG. 4.—Section from a finished interplane strut, showing a small lightning injury in Sitka spruce.

It is self-evident that wood with these lightning rings must be used with discretion. Even though the lightning ring does not check on drying, when a member with this defect is put under severe strain and stress a serious check may develop. Of course, every member showing a lightning ring need not be considered valueless. Such a defect in the stream line of a strut, for example, would be trifling, while a much shorter ring in the butt or inner bay of a wing beam, particularly if in the same plane as the bolts, would be serious. The same ring in the tip of such a beam could be overlooked.

The detection of lightning rings in rough lumber is exceedingly difficult, unless accompanied by small wounds, which is sometimes the case. Then such wounds must be scrutinized closely for the presence of a lightning ring. Two or more of these wounds, which resemble sapsucker wounds, occurring on the same annual ring and connected by a lightning ring, are sometimes found. Figure 4 shows one of these wounds on an interplane strut, in this case not of

any importance, since the injury occurred alone with only a very short lightning ring and on the stream lining where high strength is not requisite. Lightning rings are more readily detected on a member before it is sanded. In some cases the seriousness of the defect can be determined after planing but before the piece is shaped. This is usually possible when the defect runs entirely through the piece.

In white fir the lightning rings are easily detected both on cross section or on the radial face. The normal color of the summer wood is a light brown, while the lightning ring is a pronounced brown or purplish brown, which stands out strongly against the whitish sapwood or heartwood. Abundant resin ducts occur in these rings.

Lightning rings in incense cedar are dark brown in color, standing out plainly in the white sapwood, but are not so apparent, although still recognizable, against the reddish brown heartwood. Resin ducts do not accompany lightning rings in cedar.

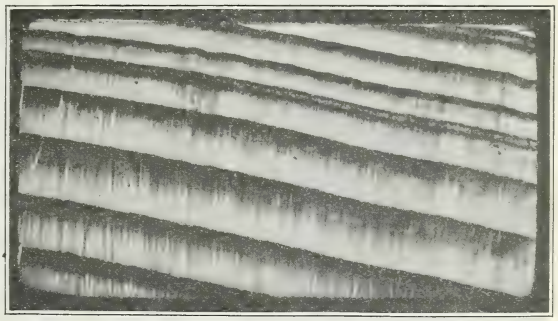

FIG. 5.—Cross section from an unfinished elevator beam, showing a lightning ring in Sitka spruce. The row of resin ducts extending entirely across the section can be seen in the summer wood of the fifth annual ring from the bottom. The defect ran the entire length of the beam.

Sitka spruce wood is rather susceptible to the effects of electricity. The lightning rings appear as light to dark brown lines in the pale pinkish heartwood or white sapwood. Rings are found which appear to be chiefly composed of resin ducts; in fact, when viewed on the end section, it is seen that the resin ducts are so numerous that they almost coalesce. This condition is illustrated in Figure 5. Furthermore, spruce wood is peculiarly susceptible to discoloration by lightning injury. Often in connection with a lightning ring a reddish brown discoloration is found, somewhat tinged with purple. This discoloration rarely extends radially more than 3 or 4 inches from the lightning ring toward the pith, but may extend 2 feet beyond the limits of the ring in a vertical direction. Wood so discolored is not weakened. Furthermore, the color is not sufficiently intense to detract from its value for any purpose, particularly since the discoloration when varnished appears merely as a darker tone of the normal heartwood.

The lightning rings found in Douglas fir are red-brown in color, darker than the summer wood and consequently are quite apparent in the white sapwood and orange-red or yellowish heartwood. These rings are practically composed of resin ducts. The ducts are smaller than in Sitka spruce.

The reader must not get the impression from what has been written that lightning rings are a feature of every piece of wood, but they do occur and must be taken into account.

SAPSUCKER WOUNDS.

Sapsuckers are a group of woodpeckers which extract the sap from the inner bark and sapwood of living trees and eat the cambium. The final result after the wound has healed or callused over is the so-called bird pecks (*15*, *35*). This injury is often accompanied by extensive staining, particularly in the hardwoods. On the ends of logs or boards the healed wounds appear as stained areas of varying size, each containing a more or less open, short, radial check in connection with distorted grain. The general appearance is a T-shaped or triangular mark or check surrounded by a stain varying from brown to almost black. More than one usually occurs in the same annual ring. On the edge-grain or slash-grain faces of sawed lumber these injuries usually appear as small knots or distortions in the grain, surrounded by more or less stain which is usually localized, but the stain may be accompanied by a bleaching which extends for some distance. The stain is always adjacent to the distorted grain, and the more distorted the grain the greater the extent of the stain.

FIG. 6.—Section from a finished longeron, showing a sapsucker injury or bird peck in white ash.

The stain appears to be the most injurious of the two, but in reality the distorted grain is the only cause of weakening in the wood. The strength of the wood is not much affected, so that wood with bird pecks in most cases can be safely utilized. Figure 6 shows a section from a white-ash longeron with a minor injury of this kind which does not impair the usefulness of the member. Pieces are sometimes unsuitable for handles, owing to the tendency of the grain to roughen up at these places when planed. If the pecks are numerous in one annual ring it is best not to use the piece, for although it has not been determined by comparative tests it is quite probable that such material is reduced in strength. Checks or wind-shakes are very prone to occur along an annual ring containing numerous sapsucker wounds or even at individual injuries. These often prove to be serious in thin veneer, since pieces of the distorted grain are likely to fall out. Sapsuckers are responsible for much of the curly grain and bird's-eye found in tulip poplar. Both stain and bird's-eye in this species are shown in Figure 7.

Practically all tree species, both softwoods and hardwoods, are subject to this type of injury, but hard maple, soft maple (*Acer saccharinum* Linn.), tulip poplar, and hickory in particular stain badly. The bird pecks are common in white ash, but the accompanying stain is generally closely localized.

PITH-RAY FLECKS.

Pith-ray flecks, which are also termed medullary spots and pith flecks, are caused by the larvæ or grubs of certain insects living in the cambium of living trees during the growing season (*10*, *17*, *20*, *21*, *44*, *67*). These insects comprise several species of the genus Agromyza belonging to the order Diptera. On the end section of logs or lumber the flecks appear as small brown crescent or half-moon

shaped areas, which on the tangential or slash-grain face and the radial or edge-grain face of a board appear as brown streaks, usually running in a vertical direction. (Figs. 8 and 9.) The wood for a little distance around a pith-ray fleck may be darker than normal. This is particularly so in poplars or cottonwoods (*Populus* spp.). On the whole, the injuries are not at all serious, having no noticeable effect on the strength of the wood unless the flecks are exceedingly

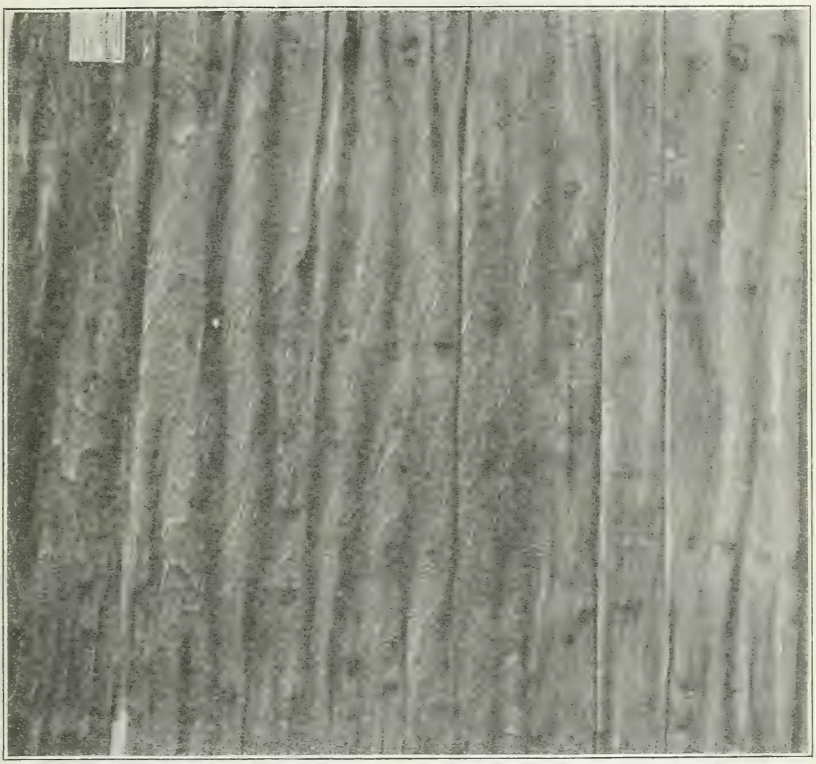

FIG. 7.—Slash-grain or tangential surface of a tulip-poplar board, showing stain and bird's-eye caused by sapsuckers. One-third natural size. (Courtesy of the U. S. Biological Survey.)

numerous. Only in the cherries (*Prunus* spp.) may a weakening be expected, for there the affected wood tissues are broken down, while in the other woods they are but little distorted. Furthermore, the presence of pith-ray flecks is usually hard to detect in the heartwood of cherries. The color of the heartwood differs but little from the color of the pith-ray flecks.

Pith-ray flecks are found in all the common poplars or cottonwoods, birches, maples, cherries, basswood, and many others, but there is considerable variation in their abundance on different closely related species. For example, these flecks are very common in soft maple, while they are rather infrequent in hard maple. In river, gray, and paper birch (*Betula nigra* Linn., *B. populifolia* Marsh, and *B. papyrifera* Marsh) they are found in abundance, but are

somewhat uncommon in yellow birch, although the writer has found them from time to time in propeller stock of this species. Softwoods

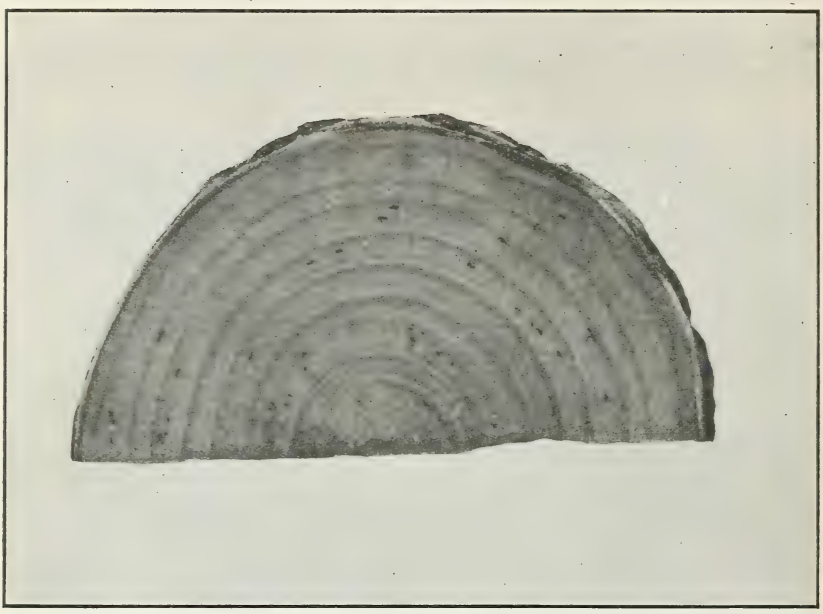

FIG. 8.—Transverse section of a branch of river birch, showing pith-ray flecks. Natural size.

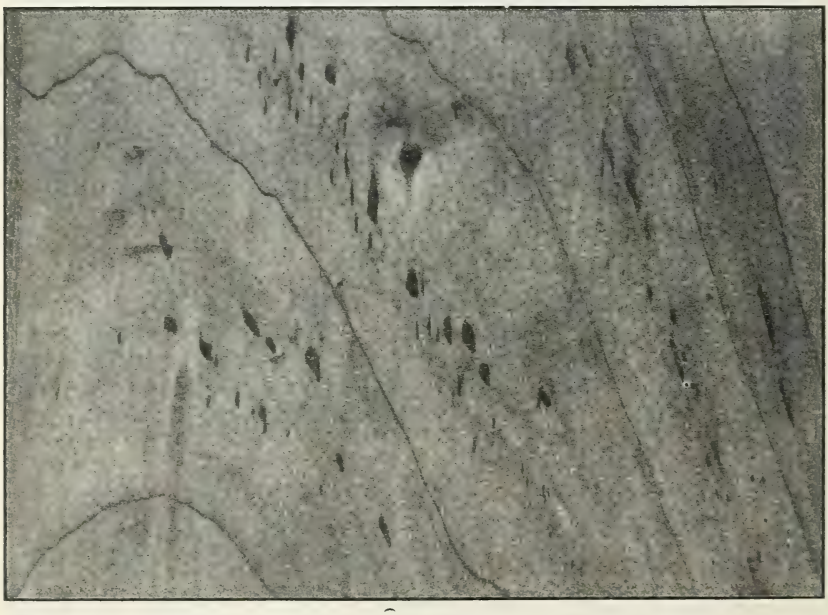

FIG. 9.—Tangential section of the trunk of a tree of silver maple, showing pith-ray flecks. Natural size.

are not subject to these pith-ray flecks, but a somewhat similar injury in western hemlock known as black check results from the work of a different insect (*11*).

CHEMICAL DISCOLORATIONS.

The sapwood of many species of wood is subject to discolorations, varying widely in appearance but fundamentally the same, which are the result of chemical action (*3*). Sapwood is rich in organic compounds and also contains certain soluble ferments which facilitate the oxidation of such compounds. Under favorable temperature conditions, for example, when green sapwood is exposed to the oxygen of the air, these ferments, known as oxidizing enzyms, act on the organic compounds in the sapwood. The result of their action, which is an oxidation process, is a discoloration of the sapwood, with the colored substance most noticeable upon microscopic examination in those cells mainly concerned in the storage and transportation of food.

Hot, humid weather is most favorable for this staining. Cool, dry weather retards it or prevents it entirely. Logs immersed in water are not affected. Light is not necessary for this reaction, as it takes place just as readily in darkness. The stain is confined to the immediate surface layer, and the wood is not weakened. The most practical method of prevention, if this is considered necessary, is by dipping the green sap boards into boiling water for a few minutes as they come from the saw.

HARDWOODS.

Birch, maple, and cherry stain a reddish yellow or rusty color. The wood of alder becomes very intensely red or red-brown on freshly cut surfaces, often within an hour or so after the surface is exposed (*40*). In the case of red alder (*Alnus oregona* Nutt.), if the wood dries and remains white, the red color will appear upon the addition of water in the presence of air, provided the temperature is favorable. A bluish stain often occurs in red gum (*Liquidamber styraciflua* Linn.).

The European linden (*Tilia europaea*, Linn.) is subject to a striking discoloration (*39*), which probably also occurs on basswood in this country. When freshly sawed boards are so closely piled that they dry slowly, a more or less apparent dirty green color appears in from 8 to 10 days. Under very favorable conditions the color is exceedingly bright and intense. The color varies between wide limits, from yellow-green or brown-green through all possible gradations to the purest moss green. Only the outer layers of the wood are colored. Usually the stain extends to a depth of one thirty-second of an inch or rarely to a depth of one-eighth of an inch. The staining, although it is the result of a chemical reaction (an iron-tannin reaction), is not dependent on temperature, since it occurs just as readily in winter as in summer. Too much moisture hinders the reaction, but a certain degree of moisture is essential. If the boards are dried quickly no staining results.

SOFTWOODS.

Coniferous woods are not so commonly subject to this type of discoloration, but there are a few examples. The ends of incense-cedar

logs sometimes have a decided brownish red stain on the sapwood. This is of no importance, because it does not occur on sawed lumber except so faintly as to be almost invisible.

A very unsightly discoloration known as brown-stain (*43*, p. 305–307), which, however, does not weaken the wood, often occurs on sugar pine, but is frequently not noticeable until the lumber has been finished. This appears in the sapwood as a streaky, dirty, light to dark brown or brownish black discoloration, and may be superficial or very deep. It is quite striking against the faint yellowish white sapwood in finished lumber. The discoloration occurs on green sap lumber upon exposure to the air and may appear during air drying or kiln drying. In the last instance it is known as kiln burn, but it does not differ from the brown-stain and is probably sometimes due to defective circulation in the kiln. Brown-stain is particularly bad in lumber cut in early spring. Hot, humid weather and poor circulation of air in the lumber piles favor the staining, while cool, dry weather and proper piling tend to prevent it. This brown stain is an oxidation process similar to the others, but whether it can be prevented by the hot-water treatment is doubtful, since the discoloration often extends deeply into the lumber.

The wood of sugar pine in dead trees, standing or down, may be affected by a very brilliant orange stain which occurs in spots or as a solid color, but more often is seen as narrow to broad streaks parallel to the grain of the wood. It is found in both heartwood and sapwood. The exact cause of this discoloration is unknown, but it is probably the result of chemical reaction, since no fungous mycelium has been found associated with it. While the wood is apparently not weakened, the presence of this stain indicates that the lumber came from dead trees, and it should be closely watched for signs of decay and insect borings.

DISCOLORATIONS CAUSED BY FUNGI.

From an economic standpoint by far the most important discolorations in wood are caused by fungi. Fungi are very simple plants which can not live on the simple food elements of the soil and air and build up complex organic matter, as is done by the green plants with which we are familiar, but must have organic matter already prepared in order to sustain life. This they find in the material built up by green plants; hence they may attack living plants, or dead portions of such plants, or any dead vegetable matter. Some live on animal matter, but these do not concern us. The development of fungi is dependent upon a supply of oxygen, of which there is always sufficient in the air, a certain degree of moisture, a suitable range of temperature, and the necessary food substances. The maximum and minimum of these requirements vary widely with different fungi.

The fungous plant consists of very fine threads (hyphæ), which are invisible to the naked eye unless they occur in mass. Individual hyphæ require magnification by a compound microscope. Collectively, the hyphæ are termed mycelium. The hyphæ usually live in the tissues of the substance on which the fungus is growing. The fruiting bodies or sporophores, which vary in size from those so small as to be invisible to the naked eye except in a mass to others quite

large and conspicuous, appear on the surface after the hyphæ have developed vigorously. The fruiting bodies bear the spores, which are microscopically small reproductive bodies of relatively simple structure. The spores, being very light, are borne about by air currents. If they alight in a suitable place under proper conditions, germination takes place and hyphæ develop.

Fungi growing on wood may be roughly divided into two groups, depending on the habit of growth of hyphæ. In the first group are placed those fungi whose hyphæ live on the substances contained in the various cells of the wood, while to the second group belong those whose hyphæ attack the actual wood substance of the cell walls and destroy it. The first group is principally represented by the sap-staining or discoloring fungi, so called because they produce various discolorations which are confined to the sapwood. To the second group belong the wood-destroying fungi.

SAP-STAIN.

DESCRIPTION.

Sap-stain, which has been extensively studied (*23*, *27*, *38*, *50*, *51*), even though it may render wood very unsightly does not reduce its strength for practical purposes. The discoloration is normally limited to the green sapwood, because as a rule there is neither sufficient food material nor moisture in the dry dead heartwood for the development of the fungus. The discoloration is usually most intense in the medullary rays, since in these tissues the bulk of the food material is found. The stain is produced in two ways, either by a reflection of the color of the hyphæ through the cell walls of the wood or by an actual color solution excreted by the hyphæ, which stains the wood itself. These stains vary in color from blue or blackish to reddish, the former being the most common. Since these fungi do not attack the cell walls in which the strength of the wood reposes, except to a negligible extent, discolored wood is not appreciably weakened. This has been determined by comparative mechanical tests on stained and unstained wood (*41*; *56*, p. 13–14; *72*, p. 17).

Although the strength of the wood fibers is not impaired by such stains, the wood is objectionable in places where color is a factor. In a highly varnished interplane strut, for example, a stained streak is unpleasant to the eye. Furthermore, it may lead to a strong prejudice against the airplane having such a member, because while by the uninitiated a dangerous defect not readily apparent is passed unnoticed, an unsightly though harmless discoloration is considered to indicate a serious weakness. Where the discoloration is to be covered up or painted there is no reason to exclude it.

It must be remembered that the conditions which promote the development of the fungus discoloration are highly favorable to the development of true wood-destroying fungi. These conditions are a comparatively high humidity and warm weather. Sap-stain is at its worst during warm wet weather, when the humidity of the air is relatively high and lumber dries slowly. It is at such periods that the most severe staining may occur if the lumber is not properly handled. The climate of the Pacific Northwest is usually exceed-

ingly favorable for the development of wood-staining and wood-destroying fungi during the spring and summer months. It is from this region that the three most important airplane woods—Sitka spruce, Douglas fir, and Port Orford cedar—are obtained.

Wood containing very severe sap-stain therefore should be carefully examined for the presence of wood-destroying fungi. If decayed, the wood will be brash and may be softer and less tough when the fibers are picked with a knife. If any doubt exists after an inspection, the decision should be based on a microscopical examination or a mechanical test by a qualified expert.

The most important of these stains from an economic standpoint is blue-stain, caused by various species of Ceratostomella, which may be found on almost any hardwood or softwood. Softwoods are more commonly affected, and certain species are particularly susceptible. This is due both to the character of the wood and to the climatic conditions of the region where the species occurs. The discoloration may be more or less superficial, occurring as spots or streaks. If the staining is severe, however, the entire sapwood will be affected, so that it can not be surfaced off. The fungi causing these stains are not readily seen, but sometimes if a deeply stained, almost black piece is inspected with a hand magnifying glass, innumerable bristles with a bulbous base will be observed. These are the fruiting bodies, containing an enormous number of spores, which are exuded and are carried about by air currents. Falling on green sap lumber they sprout, the hyphæ develop, and more blue-stain results. Under favorable conditions blue-stain may develop with surprising rapidity, appearing on lumber within a day after sawing.

Other colors, such as black, brown, gray, red, pink, and violet, are caused by species of Hormodendron, Hormiscium, Graphium, Penicillium, and Fusarium. These discolorations are not nearly so common as blue-stain.

Certain other discolorations of sapwood are produced by fungi belonging to the molds, of which the green mold on fruits or in certain cheeses is an example. Usually such stains are superficial and readily surface off. They occur on both hardwoods and softwoods. The bluish or blackish stains are difficult to separate by visual inspection from the true blue-stain.

CONTROL.

Considerable study has been devoted to the development of methods of prevention and control of sap stains caused by fungi (*1, 25, 72*). Naturally most of this work has been concentrated on blue-stain, and the following paragraphs are most directly applicable to it, but will probably also apply fairly well to the others. Blue-stain may be checked after it has started, but the stain can not be eradicated unless it is so superficial that it can be planed off. Therefore, the keynote of all treatments must be prevention.

Unfortunately, there is no one principle that can be applied to the prevention of this discoloration. Staining may take place at any time after the trees are felled or, in the case of dead timber, while they are still standing. Hence, in logging operations in regions where blue-stain is of importance, the logs should be removed from the woods as soon as possible after the trees are felled and bucked

(cut up into log lengths). The practice of leaving logs lying in the woods for months can not be too strongly condemned, as this not only causes blue-stain but also promotes the growth of wood-destroying fungi. Furthermore, the inevitable attacks of wood-boring insects assist greatly in the spread of blue-stain and decay. When the trees are bucked the narrow space left by the saw kerf between the logs as they are lying end to end affords an ideal situation for the development of the blue-stain fungi. Such logs often stain deeply, while those with the ends fully exposed remain entirely free from discoloration. As soon as the logs are in the mill pond danger from staining is over for the time being, since the oxygen supply is so reduced that the fungi can not develop.

The greatest danger of all is encountered during the process of drying the rough lumber as it comes from the saw. The best method of preventing blue-stain is by kiln drying. If the stock checks easily, so that low temperature and high humidities must be maintained over a considerable period, some of the other staining fungi such as molds, may develop. But these can be checked by raising the temperature in the kiln to about 160° F. or slightly more for an hour by turning live steam into the kiln. When this is done, care must be taken to keep the air saturated while steaming and to reduce the humidity gradually after steaming. When the stock has once been dried properly the moisture content has been so reduced that there is no more danger from staining, provided it is kept dry. A dispute that arose over the efficiency of a dry kiln was immediately settled by the fact that the blue-stain fungi had resumed vigorous growth the day after the stock was removed from the kiln. This could not have occurred if the lumber had been properly dried.

All airplane lumber should be kiln-dried immediately, since this not only prevents blue-stain, but also stops the growth of wood-destroying fungi, prevents future checking, and greatly reduces weight without in any way injuring the lumber, provided temperatures that are too high are avoided.

In case kiln drying is impossible, treatment with antiseptic solutions is of considerable value. As it comes from the saws the green lumber is dipped into a hot or cold chemical solution. The solutions most commonly employed are sodium carbonate or sodium bicarbonate in water. Neither is 100 per cent effective under optimum conditions for staining, but they aid materially in checking discoloration. These two chemicals, however, color the treated wood a decided yellow or brownish. Sodium fluorid, although it does not stain the lumber and is slightly better for blue-stain, is not so effective against certain molds as the two solutions first mentioned. This chemical is seldom used. It must be remembered that the strength of the solutions must necessarily vary with the conditions. The more favorable the conditions for blue-stain, the stronger the solutions should be.

After being dipped in any of these solutions the lumber must be carefully open piled, that is, with spaces between the boards to insure good ventilation. Narrow cross strips or "stickers" chemically treated should be used, to prevent staining at the points where the boards and cross strips meet. Detailed instructions as to the proper methods of piling lumber may be consulted elsewhere (*4*, p. 17–21).

Salt is of little or no value in preventing blue-stain in comparison with the other chemicals. The application of salt after blue-staining has well started is almost a waste of money. In fact, the application of wet salt or a strong salt solution may prove detrimental in the long run, for if the lumber is dried after such treatment the affinity of the salt for water may cause the moisture content to remain much higher than normal.

Mercuric chlorid in a 0.1 per cent solution is exceedingly effective against blue-stain, but on account of its highly poisonous nature and extremely corrosive action when in contact with many metals it is little used.

Shipping green stock closely piled in closed box cars during the spring and summer months is almost certain to result in severe staining. Indeed, the writer has seen some stock handled in this way which stained even in winter. On the other hand, any measures taken to prevent staining, such as open piling in gondolas or on flat cars, will almost certainly result in severe checking. Of the two evils, checking is by far the most serious in airplane stock, since checked lumber is greatly reduced in strength, while the stained lumber is only somewhat unsightly. Shipping green lumber in the close hold of a vessel, particularly if tropical seas are to be traversed, is an invitation to swift and sure disaster as far as sap staining is concerned. It is doubtful whether dipping in any chemical solution now used, except possibly mercuric chlorid, would be effective under such severe conditions.

But, to repeat, the most effective measure to employ against blue-stain is speed in drying the wood. Get the logs from the woods to the saw with the greatest rapidity and the lumber from the saw directly into the dry kiln.

SAP-STAIN ON SOFTWOODS.

Certain species are peculiarly susceptible to sap-stain. This is due both to the character of the wood and to the climatic conditions of the region where the species grows. Western white pine, spruce, and southern yellow pine, the last-named wood including longleaf pine (*Pinus palustris* Mill.), shortleaf pine (*P. echinata* Mill.), and loblolly pine (*P. taeda* Linn.), are very subject to sap-stain, especially blue-stain, while true fir and cedar are not so easily affected. Douglas fir occupies an intermediate position.

Besides blue-stain, a red stain has been very commonly found on Sitka spruce airplane lumber. It occurred abundantly in the East on stock in cars just arrived from the Pacific coast and also developed on material along the Atlantic coast which had arrived unstained at the port of embarkation but was held over awaiting shipment. The stain appeared as terra-cotta or brick-red spots on the rough lumber, varying from very faint to a pronounced color. In the stock worked up in the factories in this country it was found that the stain was superficial, usually surfacing out during remanufacture; but reports from abroad indicate that the fungus developed very intensively by the time the lumber reached European ports, and the discoloration penetrated deeply into the sapwood. The appearance of the wood is not marred to the same extent that it is by blue-

stain, and as far as is known no reduction in strength results. The fungus causing the discoloration is as yet unknown.

Blue-stain is very severe on the white pines and is particularly noticeable because of their white wood. Plate I, left part, shows a section from a sugar-pine rib web in which the sapwood is stained to some extent. The small, darker, bluish black spots are the ends of the medullary rays, in which, as before stated, the fungous mycelium is most abundant. The longer streaks are the resin ducts.

Certain fungi (*Penicillium* spp.), stain the sapwood of the pines an orange-red to a crimson-red color. Another fungus (*Fusarium roseum* Link) is responsible for a pink to lilac color in the same woods. The color is produced by means of a pigment secreted by the hyphæ, which actually dyes the wood.

A wood-staining fungus (*Zythia resinae* (Fr.) Karst.) has been reported in Europe (*9*) as working on finished pine lumber after the wood has been oiled. The discoloration was characterized by violet to dirty red or even dark grayish brown flecks beneath the oiled surface of the wood. The spots were covered with minute pustules varying from violet, orange, and brown to black. These constitute the spore-producing bodies. The discolored areas extend within the wood as streaks closely associated with the medullary rays and resin ducts. The report does not state whether the discoloration was confined to sapwood. Apparently the wood was not reduced in strength. As far as is known, this stain has not yet been found in the United States.

SAP-STAIN ON HARDWOODS.

Hardwoods are not as subject to the stains caused by fungi as are softwoods. In hardwoods, when sap-stain does occur, the discoloration is most intense in the medullary rays and large pores or vessels. In a wood such as yellow birch, in which these vessels are not too closely crowded, the stain, if not too severe, appears in longitudinal section as very narrow bluish black lines or streaks following the grain of the wood. This stain will not necessarily be confined to the surface layers, but may extend entirely through the sapwood. Of all the hardwoods, however, red gum seems to be the most susceptible to stains caused by fungi.

BROWN-OAK DISCOLORATIONS.

A somewhat different discoloration than those previously described, in that it is confined to heartwood only, is the "brown oak" (*18*, *19*) found in Great Britain. This is also known as "red oak" and "foxiness," but the name first given is most commonly accepted. Instead of the normal heartwood, certain trees of the common European oak have a dull-brown to rusty brown or even rust color in the heartwood. In some cases the color is uniform, while again longitudinal streaks of normal-colored heartwood may alternate with those of the brown color. When these brown streaks contain black patches this type of wood is known as "tortoise-shell" oak. This discoloration originates in the heartwood of living trees, the normal heartwood changing first to a faint yellow color, which continues to deepen until the brown stage is attained. The color change is caused by a fungus, but so far as known the infected wood is not weakened.

The hyphæ attack the cell walls very slightly, presumably living on the tannin, of which oak wood contains a high percentage. The value of the wood for veneers is very much enhanced. The writer has no record of this discoloration being found on oaks in this country.

DECAY DISCOLORATIONS.

The hyphæ of wood-destroying fungi living within the wood feed on the various substances composing the cell walls. They use certain constituents of the cell walls, neglecting others, with the result that these walls are broken down, the wood being thus greatly weakened and more or less destroyed. It is the breaking down of the wood and the change in its physical and chemical qualities that is termed decay. The degree of decay is determined by the energy of growth of the fungus, the length of time it has been at work, and the type of wood it attacks. Some fungi attack many different kinds of wood, while others are limited in their choice. Owing to their less exacting moisture requirements, wood-destroying fungi are able to live on heartwood as well as sapwood. The fruiting bodies, usually quite large, are found on the surface in the form of brackets, crusts, or mushrooms or toadstools. They are not developed until the hyphæ have been at work for some time; consequently, the presence of fruiting bodies indicates serious decay.

Two types of wood-destroying fungi may be recognized, (1) those mainly attacking the heartwood, rarely the sapwood, of standing living trees, and (2) those principally confining their activities to the manufactured product, such as sawed lumber, crossties, and poles. The former type may continue their work of destruction after the tree has been cut down and worked up into lumber. The latter, attacking the manufactured product, usually invade the sapwood first, since it is far richer in stored food, generally has a higher moisture content than the heartwood, and is not so inherently resistant to decay. Fungi causing this type of decay are often very abundant in yards where the lumber is closely piled on damp earth, with little or no aeration under the piles, and much accumulated wood débris scattered throughout the yard. Unfortunately, such conditions are all too prevalent in mill yards. Sanitary yards both at the mills and the factories are badly needed. Humphrey (*28*) gives a complete account of the life history and habits of these fungi, the damage caused by them, and methods for their control.

CONDITIONS AFFECTING DECAY.

All conditions which favor sap stains are equally favorable to wood-destroying fungi. Furthermore, the latter can attack wood with a lower moisture content, so the fact that wood does not sap-stain is no indication that fungi causing decay may not be present. The discolorations caused by the latter in sapwood are not so pronounced as sap-stain; consequently, they are much harder to detect.

Moisture in wood.—Dry lumber will not decay. The most efficient method to prevent decay is to air-dry or kiln-dry lumber immediately and then keep it dry by proper methods of storage. Placing dry lumber in the open, exposed to rain, or in damp sheds can not be too strongly condemned. If the lumber becomes moist again, it is just

as liable to decay as before. To be sure, kiln drying is much better than air drying, since the high temperatures employed in the former process are probably fatal to the hyphæ of some decay-producing fungi, while under the latter conditions the fungi may merely remain dormant until suitable moisture conditions are again restored. However, since wood-destroying fungi are common around and in yards and wood-working factories, the chances are that kiln-dried lumber will be reinfected, and if it becomes moist again decay will begin.

Shipping green or even partially air-dried lumber on long voyages through tropical seas in the hold of a vessel offers a chance for a heavy loss through decay. The close humid air of the ship's hold becomes a perfect forcing chamber for wood-destroying fungi when warm latitudes are reached. Shipments of Douglas fir leaving the Pacific coast perfectly sound have contained a considerable percentage of decayed lumber when unloaded at a South African port (*36*, p. 36). Indirect reports indicate that the same condition resulted during the World War in some shipments of Sitka spruce routed to Europe through the Panama Canal and the Mediterranean Sea.

Durability of wood.—Resistance to decay, or as it is termed "durability," is a factor that should no longer be neglected in selecting woods for airplane construction. Airplanes are being more and more exposed to unfavorable weather conditions as their use extends, conditions which in some instances are highly favorable to decay. Furthermore, certain conditions created by the construction of an airplane promote decay. For example, in the interior of the wings the relative humidity may be much higher than that of the surrounding air, and there is often considerable condensation of moisture. In addition, the temperature is slightly higher. All these factors are favorable to the development of wood-destroying fungi.

Within any species durability increases with the increase in specific gravity. Consequently, the fact that only wood with high specific gravity is used for aircraft not only increases strength but serves to increase durability. However, it is well known that different species vary widely in their durability. Unfortunately, spruce is not at all durable. Neither are basswood and birch. Douglas fir is fairly durable, as is also white oak. But the cedars are remarkable for their inherent durability, and among these Port Orford cedar compares favorably with spruce in all its strength properties and is only slightly heavier. Consequently, this wood can not be too highly recommended for use in aircraft where resistance to decay must be considered. Sapwood must not be used under such circumstances, for no matter what the species is it decays easily.

Contrary to existing belief, the resin content of wood is of slight importance in relation to durability (*74*, p. 153–154; *75*, p. 66–68). Resin itself has no poisonous effect on the growth of fungous hyphæ, and its only beneficial effect in increasing durability is its waterproofing action on wood. This is so slight, however, if the normal resin content of softwoods is considered, as to be practically negligible. If wood is rendered more durable through a sufficient increase in its resin content to have a decided waterproofing effect,

it is usually completely resin soaked or contains pitch streaks which make it unsuitable for painting or contact with fabric coverings.

INCIPIENT DECAY.

It is a simple matter to recognize well-advanced rot or typical decay. Here the changes in the wood structure due to the longer action of the wood-destroying fungus are so profound as to be very plainly apparent, but the earlier stages of decay, termed incipient decay, immature decay, or advance rot, are often far from easy to detect (*6*, *7*). In some cases detection is practically impossible without a microscopical examination of the wood.

Specific gravity is not a reliable index of decay. It has been suggested that decay in any piece of wood will be immediately reflected in a lowering of the specific gravity. But this can not be detected unless the specific gravity of the piece was known before decay commenced, a manifest impossibility in most cases. Incipient decay does not cause a sufficient reduction in the specific gravity to bring the heavier pieces of wood below the minimum set for the species. The writer has tested pieces of yellow birch, white ash, and Douglas fir with conspicuous incipient decay and found the specific gravity of the affected pieces to be from 0.05 to 0.2 higher than the minimum permissible. The same condition will exist in all species. Douglas fir with pronounced white cellulose pockets characteristic of the final stage of red-rot or conk-rot has been found in some cases to have a higher specific gravity than the minimum of 0.45. Of course, when sound such wood had a high specific gravity.

Wood is weakened by incipient decay, the degree depending on the stage of the decay and somewhat on the species of fungus at work. Furthermore, if infected material is merely air dried the hyphæ may remain dormant, ready to continue their work of destruction again if suitable conditions arise. The chalky quinine fungus (*Fomes laricis* (Jacq.) Murr.), which normally causes decay in the heartwood of various coniferous trees, either living or dead, has been found causing decay in the roof timbers of cotton weave sheds (*5*). Undoubtedly this originated from timbers containing incipient decay of this species placed in the roofs at the time they were built, where the high temperature and humidity which prevails in such sheds soon resulted in renewed activity of the fungous hyphæ and their spread to adjoining sound timbers. The rose-colored Fomes (*Fomes roseus* (Alb. and Schw.) Cke.), which is common on dead trees and is sometimes found on living trees in the coniferous forests of the Pacific Northwest, has been found to be very destructive to timbers in basements with high humidity and poor ventilation in the Northeastern States (*26*, p. 28). As a general rule, infected wood must not be used.

It is extremely doubtful whether incipient decay in one of the laminations of ply wood can be considered an important defect. In the first place, the reduction in strength would be negligible. Furthermore, there would be but little danger of the fungus ever resuming its activities, because the high degree of heat and humidity to which the ply wood is subjected during various stages of its manufacture must kill the vegetating hyphæ. However, this does not prevent reinfection and subsequent damage if conditions for decay

again become suitable. Laminations with incipient decay should not be used in propellers. In this place the reduction in strength need not be so carefully considered as the variation from the normal shrinking and swelling that would result. Unequal and particularly unusual strains and stresses must be avoided above all things in propellers.

Incipient decay usually appears as a discoloration, in some cases pronounced, in others so faint as to be practically invisible. Most of this decay in airplane lumber was actually in the tree when it was cut or in the logs when they left the woods. It is rare that any serious effort is made in the woods or at the mills to cut out incipient decay. When the logs are bucked and sawed the typical decay is usually trimmed off, leaving the less apparent incipient decay in the lumber. After sawing, the upper grades of lumber, which include airplane stock, are usually handled carefully enough at the larger mills to prevent further damage.

When decay commences in a living tree, it spreads upward in the heartwood if the infection entered at the butt, or in both directions if it occurred higher on the trunk. Very rarely do the decays in the heartwood of living trees attack the sapwood. Beyond the typical decay, that is, where the wood is decidedly rotted, extend the incipient stages of decay, which become less and less apparent as the distance from the typical decay increases. Finally, the incipient decay ends entirely. The wood beyond is then sound. The incipient decay rarely ends abruptly or evenly, but usually fades out in one or more irregular streaks, which may be short or long. It usually extends only 3 or 4 feet longitudinally beyond the typical decay, but with certain wood-destroying fungi on some hosts the incipient decay may extend 15 feet or more in advance of the typical decay. Furthermore, the latter is always bounded radially by incipient decay, and this boundary is often irregular. Boards sawed from diseased trees may contain all stages of decay or incipient decay, occupying part or all of the board. The fact that the fungi causing decay in standing trees may continue their work of destruction in logs in the woods, or even in sawed lumber if conditions are favorable, indicates the necessity for having logs removed from the woods, sawed, and the lumber dried with reasonable promptness.

When lumber is green the discolorations indicating incipient decay are more intense than when the wood has seasoned for some time. During the drying process the discolorations fade in varying degrees. Furthermore, if a new discoloration appears within one or two weeks after the lumber comes from the saw it is practically certain that it is not caused by one of the wood-destroying fungi attacking the piled lumber, since the latter work more slowly. A sap-staining fungus or a chemical reaction is the most likely agent in such a case.

Incipient decay should be detected and eliminated before the lumber is worked into individual parts. If the entire piece is not defective the sound portion can be sawed out and utilized. In marking a piece for cutting, however, it must be remembered that decay extends more rapidly with the grain in a tree or piece of wood than it does across the grain; thus, to be perfectly safe, an allowance of 2 feet should be made in the direction of the grain beyond

the last visible evidence of incipient decay, while across the grain an allowance of 2 to 3 inches will suffice.

TYPES OF DECAY IN LIVING SOFTWOOD TREES.

One of the most common decays in airplane lumber is that caused by the ring-scale fungus (*Trametes pini* (Brot.) Fr.) in the heartwood of living trees. It may occur in practically any species of softwood, but is very common in Douglas fir, spruce, and pine. The decay, known under various common names, such as red-rot, red-heart, conk-rot, white honeycomb rot, pecky wood-rot, and ring-scale rot, is readily recognizable in its typical stage by the fact that the heartwood is honeycombed with small white pits in which the wood is reduced to a soft fibrous mass of cellulose (in a chemical sense cotton is practically pure cellulose), these pits being separated by firm and apparently sound wood. Plate II shows typical decay in Douglas fir.

While the typical decay is closely similar in appearance in various species of wood, there is considerable difference in the incipient decay. In Douglas fir as a general rule it appears as a pronounced reddish purple or olive-purple discoloration, gradually tapering and becoming fainter until it is lost entirely. The color is often most pronounced in the outermost heartwood just where it joins the sapwood. In some cases it appears brownish against the red or yellow heartwood. At the lower limits of the incipient decay, where it begins to merge into typical decay, a close scrutiny will usually reveal faint indications of the cellulose pits. Vertically the discoloration may extend 10 feet or more in advance of the cellulose pits, but radially this is limited to 2 or 3 inches. The discolorations described are often bounded by a narrow zone of pronounced red color. Plate III shows discoloration in Douglas fir with the formation of cellulose pits beginning. In rare instances the first indication of the decay may be the tiny golden white spots or streaks which indicate the initial stage in the formation of cellulose pits. In this case the discoloration is probably too faint to be recognized, and material of this kind is quite easily overlooked.

In white and red spruce (*55*, p. 32) this incipient decay first appears as a change in color from the pale yellowish or reddish brown of the normal heartwood to a light purplish gray, which deepens to a reddish brown, with the gray forming the outer boundary of the reddish brown discolored portions. Next, the cellulose pits appear, visible at first as very tiny black lines following the grain of the wood, but soon revealing their true nature. The discoloration is not so pronounced as in Douglas fir. In Sitka spruce the tiny black lines preceding the cellulose pits are not found.

The yellow pines first show the decay by a pronounced pink color which rapidly gives way to a red-brown; hence the names red-rot and red-heart. During this stage the wood is hard and firm. Then the white pits develop, although in some cases they appear so sparingly that they are readily overlooked.

In certain woods there is little or no discoloration with this incipient decay. This is true with incense cedar, Port Orford cedar, and western red cedar, and is probably the same with other cedars. The first indication of the diseased condition of the wood is the appear-

ance of cellulose pits. Hence, the purplish red color commonly found in the heartwood of incense cedar (see p. 16) and western red cedar need not be mistaken for decay.

As yet very little is known in regard to the reduction in strength due to incipient decay caused by the ring-scale fungus. However, it seems probable that such reduction is slight until the appearance of the white cellulose pits; but it is to be remembered that pieces with discoloration contain hyphæ which may again attack the wood, if suitable conditions arise. Consequently, stock with any stage of this decay should not be used.

The chalky quinine fungus causes a pronounced decay in the heartwood of many softwoods. The typical decay is a brownish red friable crumbly mass, often with conspicuous mycelium felts filling the cracks. This is shown in Plate IV. The incipient decay is very difficult to detect, as a rule. Even when the wood has been severely weakened the extremely faint brownish discoloration is not discernible to any but the most expert eye. However, the incipient stage of this decay in western yellow pine appears as a red-brown or pronounced brown discoloration in the pale-lemon to light orange-brown heartwood. The discoloration is not uniform over the entire affected portion, but may occur on the radial or tangential face in broad bands of varying intensity or even intermingled with narrow bands of the normal light-colored heartwood. In cross section the infected wood presents a mottled appearance. The horizontal limits of the discoloration are bounded by a narrow band of pronounced pink or red. At the upper limits of the incipient decay the discoloration becomes fainter until it finally disappears. The discolored wood seems to be hard, firm, and strong, but in reality it is seriously weakened. Plate V illustrates this condition.

The typical decay caused by the sulphur fungus (*Polyporus sulfureus* (Bul.) Fr.) is very similar to the foregoing. However, it is not confined to softwoods. It is common only in the true firs among the softwoods, but is very prevalent among the hardwoods, particularly the oaks. The heartwood of living and dead trees is affected. The incipient decay is difficult to detect, being first indicated by a faint brownish discoloration.

The velvet-top fungus (*Polyporus schweinitzii* Fr.) also causes a reddish brown friable rot, which is, however, confined to the butt and roots of the tree. The mycelium felts are very fine and inconspicuous. Only softwoods are affected. Normally the incipient decay is very difficult to detect. It first becomes evident in Sitka spruce[6] as pale-yellow to lemon-yellow streaks or spires extending longitudinally beyond the light yellowish to reddish brown discoloration which characterizes the more visible incipient decay. In the latter stage a softening of the wood is apparent. In Douglas fir the incipient decay is first evident as a faint yellowing or browning of the normal heartwood. This or an exactly similar decay in western red cedar is first indicated by a decided deepening in the color of the normal brownish heartwood. The discolored zone often extends horizontally for several inches around the typical decay and for a foot or more in advance of it. The discoloration may be confused with the normal

[6] The description of the decay in this species caused by *Polyporus schweinitzii* is based on notes furnished to the writer through the courtesy of E. E. Hubert.

darker colored bands of heartwood which are found in some trees, but such bands are confined to a definite group of annual rings.

Redwood is subject to a brown friable decay which is not confined to the butt of the tree. The fungus causing this is unknown (*57*). The first indication of the incipient decay is a very faint light brownish discoloration on the light-cherry to deep reddish brown heartwood. This is most readily detected on the tangential face in the summer wood. When the brownish discoloration is plainly apparent, the decay has progressed so far that the affected wood feels softer than the normal to the thumb-nail. The typical decay is dark brown in color, very soft, and easily crumbled. Thin crustlike mycelium felts occur along the sides of the cracks.

These reddish brown or brown friable decays which are so difficult to detect in their incipient stages, particularly in woods with a pronounced reddish or brownish heartwood, reduce the strength of the wood far more seriously than incipient decays of the red-rot type; in fact, the wood may be weakened before the incipient decay is visible. Consequently, in cutting out such decays from lumber it is advisable to leave a margin of safety of at least 2 feet in a longitudinal direction beyond the last visible evidence of the incipient stage.

Incense cedar is very commonly decayed by the incense-cedar dry-rot fungus (*Polyporus amarus* Hedgc.). The typical decay consists of vertically elongated pockets, varying in length from half an inch to about a foot, which are filled with a brown friable mass, and the line of demarcation between the sound and decayed wood is very sharp. In some of these pockets small cobweblike or feltlike masses of white mycelium occur. The pockets are separated from each other by what appears to be sound wood, although in some cases streaks of straw-colored or brownish wood may extend vertically between two pockets. This is especially noticeable between young pockets. The pockets of incipient decay are at first firm and very faintly yellowish brown. This color deepens slightly, and the wood becomes somewhat soft. The incipient decay extends but a short distance vertically in advance of the typical decay, and a distance of 2 feet beyond the last visible evidence will usually exclude all decay. The incipient decay is only faintly apparent, occurring as it does in pockets with the color in the very earliest stages differing but slightly, when at all, from the normal wood. The fact that an occasional pocket may be found several feet in advance of the main body of decay makes this decay an exceedingly dangerous one. The wood, even in an incipient pocket is decidely weakened (although the intervening wood is apparently not affected), and this makes a weak spot that is hard to detect. Such cases are fortunately not common, and the fact that most incense-cedar stands are so badly decayed will probably preclude this species from any extensive use for airplane construction. Other woods are subject to similar decays. That found occasionally in western red cedar may be caused by the same fungus, while "peckiness" of bald cypress (*Taxodium distichum* (Linn.) Rich.) results (*33*) from the work of a different organism (*Fomes geotropus* Cke.).

One of the most striking discolorations indicating decay and at the same time one of the most serious incipient decays is that caused

by the Indian paint fungus (*Echinodontium tinctorium* E. and E.). This is found on the true firs in the western United States, being especially prevalent and severe on white fir (*37*). It is also exceedingly serious on western hemlock (*71*).

In white fir the first indications of this decay on a radial or tangential section are light-brown or golden tan spots or larger areas of discoloration in the light-colored heartwood, which may be accompanied by small but clearly distinct radial burrows, resembling somewhat very shallow insect burrows without the deposit of excrement. These burrows are not easily detected in cross section. Next, rusty reddish streaks appear following the grain. Throughout this stage the wood appears firm and strong, but in reality is so greatly weakened that boards may separate along the annual rings when dried. The discoloration intensifies, the wood becomes soft, showing a decided tendency to separate along the spring wood in the annual rings, and finally the typical stage is reached, in which the wood is brown, with pronounced rusty, reddish streaks and becomes fibrous and stringy. Hence, the name stringy brown-rot is applied to the decay. The incipient decay usually extends from 2 to 6 feet beyond the typical decay. Plate VI shows the incipient decay.

In western hemlock the incipient decay is much harder to detect, because the initial discoloration above described so closely approximates the pale-brown, slightly tinged with red, color of the normal heartwood. The wood first assumes a faint yellowish color, which is sometimes intensified by the presence of small, hardly discernible brownish areas. These areas later develop into the typical decay. The extension of the incipient decay beyond the typical decay varies from 1 to 5 feet. For the sake of safety 2 feet should be added beyond the last recognizable yellowish discoloration in order to eliminate all incipient decay.

TYPES OF DECAY IN LIVING HARDWOOD TREES.

Hardwood trees are subject to very serious decays. One of the most important from our standpoint is the white heartwood rot (*58*) so commonly found in commercial white-ash stock, caused by the ash Fomes (*Fomes fraxinophilus* (Pk.) Sacc.). This fungus attacks the heartwood of living trees and produces a very characteristic rot. On cross section the first indication of the decay is a light brownish discoloration, often difficult to distinguish from the normal grayish brown or reddish brown heartwood. This discoloration is most apparent in the broad bands of summer wood. Next, there is a bleaching of the spring wood, during which it turns to a straw color, and then small white spots or specks appear. On the radial (edge-grain) and tangential (slash-grain) faces these appear as small whitish spots, streaks, or blotches, usually following the grain, but some may be at right angles to it if the decay follows a medullary ray. The whitish color becomes more marked, until the entire spring wood is affected and appears disintegrated. Then the fibers fall apart. The summer wood passes through the same process, but much more slowly, thus during the earlier stages of the typical decay causing a banded appearance. The completely rotted wood is whitish or straw colored, very soft, and spongy, readily absorbing water. A section

from a white-ash longeron with this incipient decay is illustrated in Plate I, right side.

Apparently mycelium does not occur in the brown discolored wood in advance of the white spots. It would seem that the wood is not weakened until the white spots are found, and the wood with the brown discoloration alone need not be rejected. It is an excellent hint for close scrutiny of an affected piece, however. The incipient decay is somewhat obscured in rough lumber, but is usually readily apparent on smooth surfaces. This stage does not extend many feet beyond the typical decay, and on long boards the latter will most likely also occur. Once the presence of the typical decay is ascertained it is a relatively simple matter to determine the limits of the incipient stage.

Areas in which the wood failed to change color upon transition from heartwood to sapwood (see p. 16) can be differentiated from the initial stages of white-rot by their larger size, by the straw-yellow color as opposed to the whitish of the decay, by the sharp line between the two colors, and by the fact that the spots are much larger, without becoming soft and spongy, than would be the case with the decay.

Sweet birch and yellow birch are subject to a white heart-rot (*32*) which, although very similar to the foregoing, is caused by a different fungus, the false tinder fungus (*Fomes igniarius* (L.) Gill.). The first indication of the incipient decay is a brown discoloration, not very apparent against the reddish brown heartwood. Next, faintly paler streaks or spots appear, which finally become a yellowish white, strikingly apparent against the dark background. This stage is illustrated by Plate VII. In the center of these streaks small spots are found in which the yellowish white wood appears to have collapsed. Usually the long axis of these spots is parallel to the grain, but in some it may be at right angles to it. The wood up to this time appears firm and hard. Next the white streaks merge, the wood becomes soft, and finally the entire affected portion of the heartwood is reduced to a yellowish white fibrous mass composed principally of cellulose, the result of the delignification by the fungous hyphæ. As in the white-rot of ash, hyphæ are not found in the brown discoloration. Hence, no reduction in the strength of the wood may be expected until the very first indications of the whitish streaks or spot, which may be found as much as 8 feet in advance of the typical decay.

One of the most common decays (*24*) on oaks and also on certain poplars (Populus) is the heart-rot caused by the oak fungus (*Polyporus dryophilus* Berk.). The incipient decay of this whitish piped rot in white oak has a water-soaked appearance in the unseasoned wood, but when dry the discoloration becomes hazel to tawny in color. The discoloration may extend from 1 to 10 feet in advance of any other indication of the decay. The next stage of the decay, which is best seen on a radial face, is characterized by whitish spots or streaks, usually following the medullary rays, which produce a mottled appearance of the wood. This mottling is the result of a delignification process; that is, the lignin is removed from the wood, leaving only the cellulose. In the final stages the decayed wood is firm, with a white, stringy appearance, and the delignification is practically complete.

A somewhat similar rot in oaks (*34*) is the honeycomb heart-rot (*Stereum subpileatum* B. and C.). As in the whitish piped rot, the first indication of this decay in white oak is a slight water-soaked appearance of the fresh heartwood, and when dry this "soak" becomes a tawny color. Next, light-colored isolated areas appear in the tawny discolored wood, and pronounced delignification occurs. This is indicated by the appearance of very small irregular whitish patches in the light-colored areas. These patches develop into small pits with their long axes parallel to the grain of the wood, and they increase in number until the affected wood is completely occupied. The pits are from one thirty-second to one-fourth of an inch wide by one-fourth to five-eighths of an inch long, and lined with cellulose fibers. At this stage the appearance of the decay is similar to the red-rot in softwoods previously described. Later the cellulose lining may disappear. The wood is probably not weakened by this decay until the light-colored areas appear in the tawny discoloration.

An incipient decay is sometimes encountered in African mahogany, the cause of which is unknown to the writer. This decay appears as light-yellow, brown, or merely lighter brown closely crowded spots or flecks on the reddish-brown heartwood. These flecks vary from one-sixteenth to one-quarter of an inch long and are several times longer than broad, the long axis corresponding with the direction of the grain in the wood. Such wood is weakened.

TYPES OF DECAY IN LOGS AND LUMBER.

In addition to the wood-destroying fungi which normally attack living trees, and which may continue to decay the wood after the tree is cut, there are fungi which grow only or principally on wood in the form of logs or lumber. Owing to their destructiveness, some of these deserve more than passing mention. Although it is true that damage caused by such fungi is due to improper handling of the timber during the course of manufacture and utilization, unfortunately such improper handling does occur and must be reckoned with.

Softwood logs and lumber.—One of the most important of these fungi is that which causes dry-rot in stored logs or lumber and in timber in structures (*22*). The term "dry-rot" is loosely applied to cover almost any type of decay, but it is correctly applicable only to the work of the dry-rot fungus (*Merulius lacrymans* (Wulf.) Fr.). This decay is more common on coniferous woods than on hardwoods. The incipient decay appears as a yellow-brown discoloration not easy to detect. Wood with typical decay is yellow to brown in color, much shrunken and cracked, and is so badly disintegrated that it can be easily crushed to a powder. Both sapwood and heartwood are attacked.

Another common decay on logs and sawed lumber, particularly on railroad ties, is the brown-rot (*62*) caused by the brown Lenzites (*Lenzites sepiaria* (Wulf.) Fr.), which is practically confined to coniferous wood. The typical decay is brown, friable, and easily reducible to a powder. In the early stages of decay infected wood is darker in color than the normal. Sometimes the early spring wood of the annual rings may be completely decayed, while the

summer wood is scarcely affected. In this condition the wood separates readily along the annual rings.

Hardwood logs and lumber.—Certain fungi (*Polystictus versicolor* (L.) Fr., *Stereum hirsutum* (Willd.) Pers., and others) cause a sap rot very difficult of detection in its incipient stage. The typical decay is very light in weight, white in color, rather soft, and easily broken in the hands. But since the first indication of this decay is a faint whitening of the diseased wood and white is the normal color of most sapwoods, it is apparent that the initial stages may be readily overlooked. At the same time the wood is decidedly reduced in strength. The decay is most common on hardwoods, but also occurs to some extent on softwoods. Fortunately none of the fungi causing this white sap-rot attack living trees of the species which furnish airplane timber.

Red-gum logs when left in the woods for any considerable time are subject to a very serious sap-rot (*59*) caused by the smoky Polyporus (*Polyporus adustus* (Willd.) Fr.). The heartwood is comparatively durable. Boards cut from diseased logs are very characteristic and striking in appearance. Normally, red-gum sapwood is a light yellowish white, commonly with a reddish tinge. The sapwood in a decayed board has a number of various-colored streaks or lines irregularly distributed from the end of the board toward the middle. These streaks are light orange at first, but in the more advanced decay are a very light straw color (in fact, almost white) and are intermingled with lines and patches of bluish gray and the normal-colored sapwood. Black zigzag lines may extend from the ends of the board for a distance of 2 inches or more parallel to the grain. The general consistency of sapwood with this incipient decay, which may extend 2 or 3 feet in advance of the typical decay, is firm and solid. Sapwood with the typical decay is badly broken down, being soft and pulpy and without firmness.

This and other sap rots may be prevented by shortening the drying period in the woods. Coating the ends with hot coal-tar creosote immediately after the logs are cut is also effective. Where possible, all freshly cut logs, particularly those cut during the spring and summer, when the rot develops best, should be peeled. Sap rots similar to those found in the red gum are found in tupelo gum (*Nyssa sylvatica* Marsh) and in maple.

DECAY IN FINISHED AIRPLANES.

Little information about decay in finished airplanes is available. In the past there has been very small chance for airplanes to decay, because the completed machines rarely ever were stored, and their life in use was a relatively brief one; but since the conclusion of the World War immense quantities of airplane material have been placed in storage, and the average life of the machines has been materially increased by changes in construction. Under average conditions there should be practically no damage to finished airplanes by decay. When in use there is little danger from this source, owing to the fact that when not actually in flight the machines are properly housed. The wooden parts in the interior of the wings and around the engine are most susceptible. In these places there is an increased temperature and relative humidity. Keeping the machines in a dry

place when not in use will suffice in most climates. There is more danger in humid tropical or semitropical regions, particularly to seaplanes.

Serious loss can easily result to machines through improper handling while being stored or shipped. Airplanes are usually knocked down for storing and shipping; that is, the machine is taken apart, and the individual assemblies, such as the wings, tail surfaces, and fuselage, are handled separately. When shipped, these parts are carefully wrapped in heavy paper and packed in solid crates. If these crates are left out in the air, cracks open up between the boards, water may get in, and then the trouble commences. Once damp, it is almost impossible for the mass of paper wrappings to dry out unless the crate is completely unpacked. Varnish or dope does not prevent the taking up of moisture, so that the wood soon attains a moisture content sufficient for the growth of molds and wood-destroying fungi, while the other conditions within the crate, such as lack of air circulation with the resulting high humidity and the higher temperatures, are ideal for the development of these organisms. Even before the wood is decayed the elements of the ply wood are very likely to separate, owing to the action of moisture and molds on the glue. Even water-resistant glues can not permanently withstand such conditions.

There is no cure for decay, once it has started. The damaged part can be replaced and further destruction prevented, but the constant aim should be not to let decay begin. Material should not be kept in packing cases any longer than is necessary. The practice of leaving packing cases containing airplanes or spare parts in the open for several months can not be too severely condemned.

When put in storage, the parts should be removed from the cases and placed on racks, so that a complete circulation of air is possible around each unit or piece. The storage houses should be equipped with a forced-ventilation system, so that air of the proper humidity can be constantly circulated through the piles of material. The relative humidity should be maintained at 60 which will keep the wood at a moisture content of about 11 per cent, low enough to prevent decay, mold, or sap-stain.

Circumstances will arise where planes are in use or while being shipped when it will be impossible to maintain proper conditions to prevent deterioration. In the warm climate and high humidity of tropical or semitropical regions in particular this will be true. It is advisable to have planes for use under such conditions constructed from a durable wood such as Port Orford cedar. Where this can not be done, methods should be employed to make the other species more durable.

Wood may be moisture-proofed by the application of aluminum leaf. This not only prevents decay, since the wood is kept dry, but protects the glue joints from the action of moisture and mold.

As a last resort, the wood could be treated with preservatives to prevent decay. These liquids are most effective when forced into the wood under pressure. Consequently the completed individual wood parts would have to be treated before assembly. Sodium fluorid could be used on parts to be glued, while coal-tar creosote could be applied to the others. The most highly efficient of all,

mercuric chlorid, is unfortunately a deadly poison, corrodes metal, and is very difficult to handle. The subject of preservative treatment is one about which little is known as applied to airplanes.

Little information is available as to what fungi actually cause decay in finished airplanes or as to the types of decay found. Undoubtedly the fungi most concerned are those commonly attacking the manufactured product, such as the dry-rot fungus, the brown Lenzites, or the rose-colored Fomes. Fungi decaying the heartwood of living trees are not commonly found. When they do appear, this is practically proof positive that the manufacturer used wood with incipient decay in the fabrication of the wooden parts.

SUMMARY.

Among the softwoods or conifers the most valuable for airplane construction are red, white, and Sitka spruce, the last being most important on account of its large size and the consequently greater proportion of clear lumber that can be obtained. A splendid substitute for spruce, and its superior where durability must be considered, is Port Orford cedar. However, the supply of this wood is limited. Douglas fir, which is much heavier than spruce and therefore not so desirable, is also extensively used. In those parts of an airplane frame requiring great strength and toughness, hardwoods are used. White ash is best, but white oak, hard maple, and rock elm may be substituted. Hickory is principally used for tail skids. Black walnut and true mahogany are unsurpassed for propellers, but yellow birch, sweet birch, African mahogany, black cherry, hard maple, and white oak are acceptable substitutes. As the supply of timber diminishes in the future, a wider variety of woods will be acceptable for airplane construction.

All wood is subject to defects, of which one of the most serious is decay; but other defects which reduce the strength of timber must be recognized. Among these can be mentioned spiral and diagonal grain, specific gravity that is too low or too high, brashness caused by excessive temperatures during steaming or kiln drying, compression failures, shakes, pitch pockets, and insect galleries.

Decay in its incipient stage is often not readily recognized; but wood with incipient decay must not be used in airplane construction, since infected wood may be reduced in strength. Furthermore, the decay may continue if suitable conditions arise. The first indication of decay is usually a discoloration of the infected wood, but not all discolorations result from decay. Marked discoloration of the wood, particularly the sapwood, usually accompanies pith-ray flecks and wounds made by lightning and sapsuckers. Conditions favorable for decay also promote sap stains. These discolorations of the green sapwood of various softwoods and hardwoods occur in two ways: (1) By an oxidation of the organic compounds in the cells of the sapwood when exposed to the air and (2) by the attack of sap-staining fungi, the hyphæ of which feed on the organic compounds in the cells of the sapwood without attacking the cell walls except to a negligible extent. The discolorations are confined to the sapwood as a rule, but occasionally the sap-staining fungi, may discolor the heartwood slightly. For practical purposes wood so discolored is not reduced in strength.

The discolorations resulting from incipient decay may be found in the sapwood or heartwood. Incipient decay extends for varying distances beyond the typical decay. In cutting out this defect it is advisable to leave a margin of safety of at least 2 feet in a longitudinal direction beyond the last visible evidences of the incipient decay, in order to remove all infected wood. This margin of safety is particularly important with brown or red-brown friable decays, since infected wood may be dangerously weakened by them while the incipient stage is still practically invisible.

Many decays other than those described in this paper are found in living trees, in logs, and in manufactured timber, but the examples cited include both the most important decays and the principal types. For most purposes it is sufficient to recognize incipient decay as distinguished from other discolorations or defects without determining the causal fungus.

FIG. 1.—SECTION FROM A RIB WEB, SHOWING BLUE-STAIN IN SUGAR PINE.
The dark-blue specks are the ends of the medullary rays. The pale orange colored wood at the right is unstained heartwood.

FIG. 2.—SECTION FROM A WHITE-ASH LONGERON.
The brownish discoloration with the small white streaks indicates incipient white heartwood rot.

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SECTION OF THE HEARTWOOD OF DOUGLAS FIR.

The typical decay here shown is caused by the ring-scale fungus. The light-colored wood at the right is sound sapwood.

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INCIPIENT DECAY IN DOUGLAS FIR CAUSED BY THE RING-SCALE FUNGUS.
The white spots are the beginning of the formation of cellulose pits in the central discolored zone, indicating decay.

DECAY COMMON IN THE HEARTWOOD OF PINE, LARCH, AND DOUGLAS FIR.

This typical decay, with the characteristic conspicuous white mycelium felts, is caused by the chalky quinine fungus.

INCIPIENT DECAY IN THE HEARTWOOD OF WESTERN YELLOW PINE.

The discoloration indicates the presence of decay caused by the chalky quinine fungus. The pale orange colored wood at the right is sound heartwood.

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INCIPIENT DECAY IN THE HEARTWOOD OF WHITE FIR.

This golden brown discoloration indicates decay caused by the Indian-paint fungus. Note the contrast in color with the normal white wood.

SECTION OF YELLOW-BIRCH PROPELLER STOCK.
The incipient decay here shown is caused by the false tinder fungus.

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